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U.S. Bureau of Plant Industry
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U. S. DEPARTMENT OF AGRICULTURE.
BUREAU OF PLANT INDUSTRY—BULLETIN NO. 31.—37
B. T. GALLOWAY, Chief of Bureau.

CULTIVATED FORAGE CROPS

OF THE

NORTHWESTERN STATES.

BY

A. S. HITCHCOCK,
ASSISTANT AGROSTOLOGIST, IN CHARGE OF COOPERATIVE EXPERIMENTS,
GRASS AND FORAGE PLANT INVESTIGATIONS.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., October 17, 1902.

Sir: I have the honor to transmit herewith a paper on "Cultivated Forage Crops of the Northwestern States," and respectfully recommend that it be published as Bulletin No. 31 of the series of this Bureau.

This paper was prepared by Mr. A. S. Hitchcock, Assistant Agrostologist, in Charge of Cooperative Experiments, Grass and Forage Plant Investigations, and has been submitted with a view to publication by the Agrostologist.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

During the summer of 1901 Professor Hitchcock, under instructions from the then Agrostologist, Prof. F. Lamson-Scribner, visited the States of Kansas, Nebraska, Colorado, Wyoming, Utah, Nevada, California, Oregon, Washington, and Idaho for the purpose of studying conditions with reference to cultivated forage crops. In the course of his investigations he visited the experiment stations of the above States and interviewed many farmers and ranchmen, from some of whom he received much valuable information. Considerable information was also obtained from seedsmen and from dealers in grain and hay and farm machinery. The accompanying paper is a résumé of the information thus obtained. It is recognized that in a large section of country rather sparsely settled, and particularly one in which agriculture is a recent development, many farmers and others have learned much that would be valuable to others in the same section of country. The principal object of this paper is to make common property of the individual knowledge of various farmers, ranchmen, and others, so that each may benefit by the experience of others. This is particularly important in a new country such as the region described herein.

The paragraph relating to the "Inland Empire" and the last paragraph of the section devoted to velvet grass were written by the Agrostologist; otherwise the paper is entirely the work of Professor Hitchcock.

W. J. Spillman,
Agrostologist.

Office of the Agrostologist,
Washington, D. C., October 14, 1902.

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CULTIVATED FORAGE CROPS OF THE NORTH WESTERN STATES.

DESCRIPTION OF THE REGIONS.

The present bulletin discusses briefly the forage resources of that portion of the United States extending from Colorado and central California north to Montana and Washington. The whole area may be divided into several well-marked regions, each of which will be discussed separately. Each region has its characteristic climate, topography, and physiognomy. The climate depends chiefly upon the latitude, altitude, and the amount and distribution of the rainfall. The latter factor is greatly influenced by the presence and trend of the mountain chains and the direction of the prevailing winds. In general the winters are longer and more severe as the latitude increases. The climate is cooler at higher altitudes. The Coast Range, Sierra Nevada, and Cascade Mountains rob the winds of their moisture as they blow from the Pacific Ocean eastward, thus producing an arid region in the interior. The physiognomy, or general appearance, depends very largely upon the character of the vegetation, which in turn varies according to the climate and soil. The low and scattered vegetation of the sagebrush plains of the Great Basin region, the forests of the Pacific slope, and the buffalo-grass sod of the Great Plains are examples of the characteristic physiognomy. It is not the intention to discuss minutely the physical geography of the region, but these preliminary remarks will call attention to the basis of the regional classification. The relation of these physical factors to the agriculture of the individual regions will be referred to later.

The soil conditions are more local in their effect than the above-mentioned factors, but in some cases may profoundly modify the growth of plants. The soil factors may be physical, such as its ability to hold or transport water, the size of the particles, and character of the subsoil; or chemical, depending upon the chemical constituents, such as the presence of excessive amounts of carbonate of soda, salt, or other substances, producing alkali soils. One other factor should be mentioned, which, though not included among those determining the classification into areas, is nevertheless of vast importance in its relation to agriculture. This is artificial water supply or irrigation.

Great Plains.

This region extends from about the ninety-eighth meridian to the Rocky Mountains and from Texas far north into Canada. The altitude increases from about 1,500 feet, at the eastern limit, to the base of the mountains, where it may be 6,000 or 7,000 feet. The western portion of this area extends into the group of States considered in this bulletin. The topographical features of this region are discussed by the late Thomas A. Williams in Bulletin No. 12 of the Division of Agrostology, U. S. Department of Agriculture, entitled "A Report upon the Grasses and Forage Plants and Forage Conditions of the Eastern Rocky Mountain Region."

The annual rainfall is usually from 10 to 12 inches, in consequence of which the cultivation of crops is dependent upon irrigation. The native grasses are well adapted to grazing, and hence stock raising is the paramount industry throughout this portion of the Great Plains, which includes the eastern part of the States of Montana, Wyoming, and Colorado. The stock raised is chiefly cattle and sheep, vast herds of which roam over the plains during the summer, and, in most localities, for the greater part of the winter, subsisting upon the short grasses, the most important of which are buffalo grass (*Bulbilis dactyloides*) and blue grama (*Boutelona oligostachya*). Along the draws or in the valleys of the streams taller grasses occur, such as blue-stem (*Andropogon furcatus*) and alkali saccaton (*Sporobolus airoides*), the common bunch grass of the Arkansas Valley. The upland or "short" grasses seldom grow sufficiently tall for hay, but in favorable seasons hay is cut in those situations where the tall grasses abound. The foliage of the short grasses usually cures on the ground and furnishes food through the winter; but in order to provide food during the stormy periods of the winter and to increase the carrying capacity of the ranges by supplementing the natural food supply, hay is put up for winter use. This practice is increasing as competition enforces more economical methods of agriculture. Almost all the forage stored for winter is produced by the aid of irrigation. Near the base of the mountains there is an abundant supply of water in the mountain streams, and this is distributed along the valleys by means of canals. In many places storage reservoirs supply water in the canals during a portion of the period of low water.

The most important forage plant raised by cultivation is alfalfa. This can be grown up to an elevation of 5,000 or 6,000 feet. On account of the altitude the nights are too cold for the successful cultivation of corn and many other of the coarse forage grasses grown in the prairie regions to the east. Sorghum and Kafir corn are grown to some extent in Colorado for forage. Timothy is grown, especially in the mountain region; it is used for both pasture and hay. Red clover is raised in Montana and to some extent in the two States to

the south. The recently introduced awnless brome grass has shown that it can be successfully grown without irrigation. For a further discussion of the forage conditions of this area the reader is referred to Bulletin No. 12 mentioned above.

Rocky Mountain Region.

This includes a wide area passing through Colorado, Wyoming, western Montana, and a part of eastern Idaho. This area also received attention in Bulletin No. 12.

As in the preceding area, the most important agricultural industry is stock raising. Sheep raising is relatively more important here. The sheep are pastured during the summer in the valleys, or at least where they have access to water, but during the winter they may be driven to the more arid districts, depending upon the snowfall for their water supply.

The forage conditions of one of these arid regions is discussed by Prof. Aven Nelson in Bulletin No. 13 of the Division of Agrostology, U. S. Department of Agriculture, entitled "The Red Desert of Wyoming and its Forage Resources."

Alfalfa is raised by irrigation at the lower altitudes throughout the area, but, as before stated, is not successful at an altitude exceeding 6,000 or 7,000 feet, depending upon the latitude, and somewhat upon the local conditions. Above this altitude the common forage grasses of the East may be grown. Timothy is raised in Colorado in favorable locations up to an elevation of 9,000 or even 10,000 feet. On the plateau from Laramie westward the ranchmen depend largely upon wild hay for winter food. This is irrigated to increase the crop; but, owing to the injudicious or excessive application of water, the more desirable grasses are driven out by "wire grass" (*Juncus balticus*), a kind of rush.

It is a common practice to flood the land in the spring and allow it to remain partly under water until time for cutting the hay, when the water is turned off. A species of spike rush (*Eleocharis*), also known as wire grass, is common in the moist spots. This wire grass is only moderately nutritious, but yields larger crops of hay than when grown on unirrigated land, and it is less trouble to turn on the water once than to supply the water oftener, allowing it to drain off each time.

There is an impression among farmers in southern Wyoming that wild hay is more valuable for feed than alfalfa, ton for ton, for all kinds of stock. This is reflected in the price of hay at Saratoga, where wild hay or timothy sold at $15 and alfalfa at $5 to $6 per ton. At Laramie baled native hay was worth $8 to $10, and alfalfa in the stack $5 to $7 per ton. Throughout the West, grass hay is considered better than alfalfa for horses. There are several other kinds of forage plants that have been grown in isolated localities with success, and

whose cultivation should be extended. Among these may be mentioned the Canada field pea, rape, and awnless brome grass.

Great Basin.

This region extends from the Sierra Nevada Mountains to the Rocky Mountains, and from Arizona north into southeastern Oregon and southern Idaho. It is an arid region, having an annual rainfall of less than 15 inches over the greater part, and in central Nevada of less than 5 inches. The altitude of this great plateau is about 5,000 or 6,000 feet, with numerous mountain chains rising 2,000 or 3,000 feet higher. There are several lakes or depressions having no outlet, the largest of which is the Great Salt Lake of Utah.

In such localities there is usually an excessive accumulation of mineral salts, known as alkali. The water of the streams flowing into these depressions holds these salts in solution, but deposits them upon the surface of the soil when the water evaporates. These alkali soils modify the vegetation. Each species of plant is able to withstand a certain amount of alkali in the soil upon which it grows. If the amount is in excess of this limit, the plant can not exist. Consequently, the native vegetation gives a fair index of the alkaline condition of the soil. The presence of saltbushes (*Atriplex* spp.), salt grass (*Distichlis spicata*), and grease wood (*Sarcobatus vermiculatus*) indicates a strongly alkaline soil. A still larger amount of soluble mineral matter prevents the growth of even the salt plants, and in such cases the soil is devoid of vegetation.

The prevailing vegetation over the whole region, except in the mountains and upon the above-mentioned alkali soils, is the sagebrush (*Artemisia tridentata*). Hence such localities are called sagebrush plains. As in the case of the two preceding areas the chief agricultural industry is the raising of stock—cattle, sheep, and horses. The latter class of stock is of importance in certain localities, but is relatively unimportant over the whole area. The sheep are herded in the mountains in summer, where there is water, and upon the deserts in winter, where there is snow. There are vast areas where stock can not graze on account of the insufficiency of food or water, or both.

Alfalfa is grown in large quantities under irrigation in the valleys and is practically the only supplemental forage for all kinds of stock. In some of the larger valleys other crops are raised, such as grain and sugar beets. As an example, the highly cultivated Cache Valley, in northern Utah, may be mentioned. In a few favored localities dry farming may be carried on successfully. This, however, is where there is seepage and conservation of water from the winter snow on the mountains. In the Cache Valley there are numerous instances of grain and alfalfa fields on the hillsides above the canals.

Interior Valley of California.

Between the Coast Range and the Sierra Nevada Mountains lies a valley extending through central California from Kern County on the south to Shasta County on the north. This is formed by the union of two valleys, the Sacramento River flowing from the north and the San Joaquin from the south. The region is characterized by high temperature and scant rainfall in the summer. The Coast Range Mountains forming the western limit of the valley cut off the moisture-laden winds from the Pacific Ocean, except at San Francisco Bay, where there is a break in the chain through which the above-mentioned rivers reach the ocean. At this point in the valley and also opposite a few other minor breaks, the climate is modified in proportion to the amount of moisture that filters through.

When the winter rainfall is sufficient there may be an abundance of native pasture during the spring, but the main dependence is placed on two crops—alfalfa and grain hay. Excepting in a few favored localities, crops are raised by the aid of irrigation. The alfalfa is mostly consumed upon the farm, while the grain hay supplies the city markets. Alfalfa grows to the greatest perfection, especially in the San Joaquin Valley, where it is customary to obtain about 8 tons of hay at five cuttings from each acre, and about five months' pasture. Grain hay is produced from wheat, barley, and, to a less extent, from oats. In some districts, wild-oat hay is common.

Upper Pacific Coast Region.

This includes the area lying along the coast west of the Cascade Mountains, from Puget Sound south to San Francisco. It is characterized by cool summers, mild winters, and a large rainfall. Fogs are frequent and droughts very rare. The conditions are very favorable for the growth of pasture grasses, and the section is preeminently a dairy region. Through most of this region cattle can be pastured through the winter. Some hay is preserved, especially in western Washington, but on account of the dampness the quality is inferior. The Willamette Valley of western Oregon may be considered as a part of this general area, though, since it is shut off from the coast by a low range of mountains (the Coast Range), the rainfall is much less, and the climate is correspondingly modified. The annual rainfall here is 40 to 60 inches, mostly in the winter. Along the coast the rainfall is 60 inches, increasing northward in the region of Puget Sound, and it is distributed throughout most of the year. In this region the grasses and clovers that are commonly used in the Eastern States grow in great luxuriance.

The "Inland Empire."

This region, sometimes known as the Palouse country, comprises eastern Washington, northeastern Oregon, and northern Idaho. It is characterized by a dark, fine-grained basaltic soil of great fertility and of very uniform character over a wide area. The limiting factors of agriculture here are rainfall and altitude. With Pasco, Wash., as a center, where the annual rainfall is about 6 inches, the rainfall increases in all directions, attaining a maximum of about 30 inches at the base of the Blue and Rocky mountains on the east, and the Cascade Mountains on the west. A considerable portion of this area in Washington and a smaller section in Oregon have a rainfall of less than 10 inches. In this portion irrigation is practiced. In Washington, about 150,000 acres are under irrigation within this area, alfalfa being the staple hay crop, with a yield of 3 to 8 tons of hay per acre, at three cuttings. The principal irrigated areas are situated in Yakima, Kittitas, Walla Walla, and Chelan counties, Wash. Smaller areas, especially in narrow canyons along the smaller streams, are located in various parts of Oregon and Washington. The Kittitas Valley in Washington, which lies at a higher altitude (about 1,600 feet) than any other considerable irrigated area in the region in question, grows alfalfa, timothy, and clover, producing hay of excellent quality. Like all other regions between the Cascades and the Rockies, the haying season is free from rain, which fact accounts for the excellent quality of hay produced.

Those portions of the "Inland Empire" having more than 10 inches of rainfall have heretofore been devoted almost exclusively to wheat growing. In recent years considerable attention has been given to hay and pasture grasses. Brome grass (*Bromus inermis* L.) has proven to be an excellent pasture grass in this region. It also yields profitable crops of hay the second and third years after sowing. A superior quality of brome grass seed is produced here. Of the hay grasses, timothy and red clover are preferred for lowlands and alfalfa, red clover, and orchard grass for uplands. On these wheat lands, which lie at an altitude of 1,500 to 3,000 feet, alfalfa produces one or two crops a year, and is rapidly becoming an important hay crop. Irrigation is not practiced in this region where the rainfall exceeds 10 or 12 inches a year.

Heretofore, and even at the present time, the principal hay of the wheat-growing area has been a mixture of wheat and wild oats (*Avena fatua*). Where the rainfall exceeds 18 inches wild oats are troublesome in the wheat fields, particularly on north hillsides, where snow banks protect them against freezing. Hay is cut from those patches in the wheat fields where wild oats predominate. When cut green this hay is of good quality, but many careless farmers cut it so late that the seeds are mature, and the hay is not only of poor quality but

serves to scatter the seed of the pest. The common system of farming consists of taking a crop of wheat every alternate year, leaving the land idle every other year. During the idle year the land is summer fallowed; that is, plowed up in spring and left bare during summer. These fallow fields often furnish excellent wild-oat pastures, which are generally utilized.

At the present time alfalfa, clover, and brome hay are beginning to take the place of grain hay in this wheat-growing section. It has been learned that an exhausted brome-grass field can be restored to its early vigor by plowing in winter and harrowing to good tilth. After this plowing, a crop of spring grain may be taken without serious injury to the brome grass.

FORAGE CROPS.

Alfalfa[a] (*Medicago sativa*).

GENERAL CONDITIONS.

This well-known forage plant is extensively grown throughout the West in all localities where the conditions are suitable. It requires a well-drained soil and a fairly good supply of water, but will not endure an excess of water (standing water) near the surface. It thrives best where the summers are hot and dry and the winters not too cold. It will withstand a moderate amount of alkali in the soil. In the North it suffers in some localities from the effects of too cold winters, and is not usually successful above an altitude of 5,000 or 6,000 feet. It can be grown without irrigation in but comparatively few localities in the Northwest; but under irrigation it is extensively grown in all the States of this region, and reaches its greatest perfection in the hot, dry valleys of California, where the summer season is long, the water supply abundant, and the soil well drained. Alfalfa will not succeed on acid soils, but these are of rare occurrence in the western part of the United States.

Alfalfa is a perennial leguminous plant, a native of western Asia, but cultivated in the Old World for ages. It was brought to Mexico by the Spaniards and from there spread into South America and north along the Pacific coast, and then throughout the interior arid and semi-arid regions. The name alfalfa, of Arabic origin, was given by the Spaniards and is in common use throughout western America. In Europe the same plant is known as lucern, a name which is common in the eastern United States, and also in Utah and the adjacent parts of Idaho and Wyoming. In the latter region the name is commonly pronounced with the accent on the first syllable.

[a] For further description see Farmers' Bulletin No. 31.

Being a legume, it gathers nitrogen from the air by means of its root nodules, and hence acts as a soil renovator. Although alfalfa is a perennial, a field usually deteriorates after a few years from various causes. Fields in California as much as 27 and in Nevada from 35 to 40 years old are reported, but in most cases they require renewing much earlier. Often the alfalfa fields become infested with weeds. The squirrel-tail grass (*Hordeum jubatum*)—also called foxtail in Wyoming, barley grass in Utah, and tickle grass in Nevada—is common in alfalfa fields of the Great Basin and Wyoming plateau region, and wild barley (*Hordeum murinum*)—also called barley grass and foxtail—on the Pacific slope.

These two grasses are especially troublesome on account of the long bristles attached to the chaff. When mature they cause serious irritation in the mouths of animals eating hay containing the weed. In the Cache Valley and in western Wyoming the common dandelion is very troublesome. It thrives along irrigation ditches and invades the alfalfa fields to such an extent that usually the fields are plowed up in from five to eight years and renewed. This is done in the fall and oats are sown the following spring, after which the fields are again seeded down to alfalfa.

Many express the opinion that under favorable conditions an alfalfa field will last indefinitely and continue to yield profitable crops if properly handled; but the alfalfa may be killed in spots due to the trampling of stock if a field is overpastured, or, during irrigation, certain portions of the field being lower, may remain saturated with water for too long a period. Alfalfa will scarcely survive standing water longer than forty-eight hours. When alfalfa dies, its place is likely to be taken by the before-mentioned pernicious weeds.

Some growers renew their fields by disking the bare spots in the spring and sowing seed thereon, or even disking the whole field. Disking is to be recommended, as it cuts the crowns vertically and causes them to send out new stems.

FEEDING VALUE.

In the great alfalfa districts of the West this forage plant furnishes the chief and often the only food for stock besides the native pasture. It is fed to growing stock and to fattening stock; to cattle, sheep, horses, and hogs; even the work horses upon the ranches may receive no grain in addition to the allowance of alfalfa. Horses that are worked hard upon the road, such as livery teams, usually receive a small quantity of barley, and this grain may form a part of the ration for the work horses upon the ranches. Rolled barley is the form in which it is usually fed, as in this condition there is said to be less waste than when whole or ground. For this purpose the grain is passed through heavy rollers, which crush it without grinding it.

There is much difference of opinion among farmers as to the value of alfalfa for horses. Some prefer timothy or wild hay, together with grain; some feed alfalfa and grain, while others maintain that horses do well enough upon alfalfa alone. It is usually admitted that for hard work, horses should be given at least a small allowance of grain.

In Wyoming some ranchmen claim that wild hay gives a firmer flesh than alfalfa, and thus, even when feeding the latter to cattle being prepared for the market, the stockmen will feed wild hay for about two weeks prior to shipment. Some feeders finish by adding grain to the ration. For this purpose barley is used, as it is the only grain available through most of the Northwest. The seasons are too short or the nights too cold for the successful cultivation of corn, the standard feeding grain of the region to the east, and freight rates make this grain when shipped too expensive for use. At Fort Collins and adjacent parts of Colorado large numbers of sheep are fattened for the market upon alfalfa and corn. It is said that about 300,000 were fed in that vicinity during the winter of 1900–1901. Lambs weighing 35 or 40 pounds are brought from the ranges of New Mexico and fed from about the 1st of October until sold, which may be anywhere from February to June. The yearlings will then weigh from 70 to 90 pounds. It is stated[a] "that 40 acres of alfalfa will keep 300 sheep when pastured upon it. There is danger of bloating at first, but as soon as the sheep have become accustomed to it this danger ceases. Forty acres of alfalfa and 20 acres of grain will feed 450 to 500 head."

In many parts of the Great Basin it is customary for feeders to buy alfalfa in the stack for winter feeding, paying a certain amount per head per day. Conveniences for weighing are usually lacking, and this method seems to be satisfactory. At Lovelocks, which lies in one of the great alfalfa districts of central Nevada, the price for cattle was 7 to 8 cents per head and for sheep 1 cent per head per day. In Nevada, and also in some other districts of the Northwest, the stock cattle are kept upon the range during the winter, though the ranchmen try to provide a supply of alfalfa or wild hay for use during snowstorms. A selection is made from the herd, however, of those that are to receive winter feed with more regularity. These are the weaklings, the heifers with calf, and the cows with calves by their sides. It is also customary to feed only the old or weak sheep during the winter, the remainder being turned upon the deserts for their winter range.

Some common forms of racks for feeding alfalfa to cattle and sheep are shown in Pls. V and VI.

Though some maintain that grain hay is better for feeding cattle, ton for ton, than alfalfa, the majority of feeders state that the reverse has been their experience. Mr. G. F. Chapman, of Evanston, Wyo., states

[a] Agricola Aridus, published by the Colorado Agricultural College, I, p. 24.

that he has many times tried to raise cows with calves upon wild hay, but that the calves often die of starvation, while when fed upon alfalfa both cow and calf remain in good condition.

SEEDING.

The soil should be well prepared and finely pulverized, as the young alfalfa is a tender plant. In those localities where the rainfall is depended upon for the water supply, the seed should not be sown until a rain has moistened the soil thoroughly and thus placed it in a condition to favor germination. In California the rains come with such regularity that the seed may often be sown in advance of a rain and thus get the full benefit of the favorable conditions.

The seed is sown in the spring, except in central California, where it may be sown in either fall or spring. In California a common method is to irrigate, if necessary, in September or October, prepare the soil, and then to sow the seed broadcast with barley, or sometimes wheat. There is some danger from frost, and the grain is thought to protect the alfalfa. It is best not to pasture the alfalfa the first season, but to allow it to obtain a good start for the second season. If sown in the spring, the grain is usually omitted.

In other parts of the Northwest, alfalfa, though sown in the spring, is sown either alone or with grain—barley, wheat, or oats. Mr. W. P. Noble, of Golconda, Nev., states that alfalfa is sometimes sown with timothy in central Nevada. Sowing with grain has the advantage that there is a return from the land the first season, while the alfalfa is getting started. When sown with grain it is best not to pasture the alfalfa or cut it for hay the first season. After harvesting the grain, the alfalfa should be irrigated, and for this reason the grain should be removed from the field as soon as possible.

On the other hand, many prefer to sow the alfalfa alone, as in this way a better stand is obtained. Under favorable conditions one cutting may be obtained the first season, but it is not best to draw too heavily upon the field the first year either by cutting or pasturing the crop. Where the ground is weedy, it may be necessary to cut the weeds in the summer; but a still better plan is to previously free the soil from weeds by proper methods of cultivation.

When alfalfa is sown with grain, the two may be sown at the same time by means of combination machines which drill the grain and alfalfa through the same holes or scatter the alfalfa broadcast in front of the grain drill, or the alfalfa may be drilled one way and the grain cross-drilled, or the two may be sown broadcast and harrowed in separately. The amount of seed recommended by alfalfa growers varies from 12 to 30 pounds per acre. When the seed is drilled in, the amount required is less than when sown broadcast. The larger quantities of seed tend to produce smaller stems and the hay contains

less waste. Under average conditions 20 pounds per acre sown broadcast should be sufficient, if it is evenly distributed and covered to a uniform depth; but a few pounds more per acre may be sown to insure a good stand. Where alfalfa is grown for a crop of seed, a less quantity should be sown than where a permanent meadow is desired.

MAKING HAY.

As stated, it is best not to cut a crop of alfalfa hay the first season, but to allow the field to get well started for the next year. However, under favorable conditions, especially in California, one or even two or three crops of hay may be obtained the first year. The grower must use his judgment as to whether a crop can be taken from the field to advantage. In California it is customary to make two cuttings if the seed was sown in the fall with grain; the first cutting consists mostly of grain, and the second of alfalfa. After the first year the number of cuttings depends upon the length of the season and the altitude. At the higher altitudes or latitudes not more than two cuttings may be possible, while in the upper San Joaquin Valley in California five or six cuttings are usually obtained, and as high as ten cuttings are reported. The fields are usually irrigated once for each cutting, either before or after. If the irrigation is made after the cutting, sufficient time should elapse to allow the growth to commence, or there is danger of scalding. At Newman, which is in the center of the alfalfa district of the San Joaquin Valley, the first cutting is made about May 1, and others at intervals of four to eight weeks, six weeks being about the average. The last cutting is made in September, after which, for about four months, the fields are pastured. The yield of hay here for the season is about 8 tons per acre, though some farmers state that only three or four cuttings were made, yielding 5 tons. The opinion was expressed that the fields were often pastured too much. On the high plains of southern Wyoming only two cuttings are usually made, yielding about 5 tons of hay per acre. In the Lovelock Valley, Nev., where large quantities of alfalfa are grown, three cuttings are made, with a yield of 5 to 7 tons.

Alfalfa hay is prepared in the manner usual for hay crops, but the operations are modified somewhat by the climatic conditions prevailing in the dry regions of the Northwest. One man with a team can mow about 15 acres per day. The alfalfa is usually raked within a few hours after mowing, thrown into bunches by hand, and stacked as soon as convenient. If the hay is allowed to remain too long in the swath or windrow, too much loss of foliage occurs in stacking on account of the dryness of the air. The stacks may be put up in the field or near the corrals, according to convenience. If the fields are pastured during the latter part of the year, the stacks are inclosed by a fence. In some

sections, especially in California, where there are winter rains, the hay is often stored in barns or sheds.

The hay is usually stacked by machinery. If the stack is made in the field, sweeps or bull rakes are occasionally used for hauling the bunches to the stacks, but these implements have the serious objection of shattering the leaves, causing corresponding loss of valuable fodder. For this reason the bunches are usually loaded by hand on wagons provided with hay racks (Pl. IV, fig. 1). At the stack the hay is unloaded from the wagons by horsepower, the machine used for this purpose being called a stacker or hay derrick.

The most common type of stacker throughout the Northwest is some modification of the pole, or mast and boom, stacker. This is essentially a derrick, with pulleys and a hay fork, by which several hundred pounds of hay can be lifted from a wagon and deposited upon the stack. Pl. II, Pl. III, and Pl. IV, fig. 2, show some of these forms. The stackers are generally homemade. The derrick may be supported by a heavy framework or may consist of poles held in place by guy ropes. The hay is usually lifted by means of a fork, but nets are in common use in some localities. The most common style of fork is that known as the Jackson fork, or, outside of California, as the California fork. For alfalfa the fork usually has four tines, but for grass hay five or six tines. By means of a small rope the operator upon the wagon can dump the fork load of hay upon the stack at any desired point. (See Pl. I, fig. 1.) One or two horses attached to the lifting rope or cable furnish the power to lift the load. The load on the fork is swung over the stack by slightly leaning the derrick toward the stack. The fork then swings by its own weight. The empty fork is drawn back to the wagon by means of the dump rope. Sometimes the load is swung over the stack by hand. Another form of fork occasionally seen is the harpoon fork. Instead of the fork there is sometimes used a net, also called a sling or hammock. Three or four of these are placed at intervals in the hay as it is being loaded. At the stacks, the nets full of hay are lifted from the wagon to the stack by means of derricks.

Another form of stacker which has proven very satisfactory is the cable derrick. Pl. I, fig. 2, illustrates this form. Forks or nets may be used with this style. In eastern Colorado and parts of Wyoming an improved stacker was in common use.

The bunches may be brought to the stacker with horse sweeps, but the distance must not be great or there will be too much loss of leaves. Hence the stacks are smaller than when the bunches are brought by wagon.

The stacks of alfalfa are commonly made about 25 feet wide and high, and as long as convenient, often 100 or more feet.

Throughout most of the alfalfa region the hay is put up during the dry season, and the process can therefore go on without fear of

interruption from showers. Hence no pains are taken to top off the stack in order to shed rain until the stack is finished.

Turkestan Alfalfa.

Turkestan alfalfa, a variety recently introduced from Russian Turkestan by the U. S. Department of Agriculture, has been tried in many parts of the Northwest, but over most of this region it appears to have no superiority over the kind already grown. Experiments seem to show, however, that it is somewhat more resistant to cold than the common variety; hence it is likely to be better adapted to the colder portions of the area, such as Washington, Oregon, and Idaho.

Timothy (*Phleum pratense*).

This standard grass is extensively grown in many parts of the Northwest, particularly where the climate is too moist and cool for alfalfa, such as the mountain districts and the Pacific coast plain west of the Coast Range. It is the most commonly cultivated grass in the Rocky Mountain region, thriving in the higher altitudes where alfalfa is not successful. Except in favored locations, the fields must be irrigated. Timothy will not usually succeed in the hot, dry valleys of California and the southern portion of the Great Basin region, even when irrigated. In the irrigated regions of central Washington, timothy is an important crop, being grown chiefly above 1,200 feet altitude. The Ellensburg district of the Yakima Valley is famous for the excellent quality and large quantity of timothy grown for shipment. On account of the dryness of the air the hay retains its fresh green color, while that grown in the very moist regions around Puget Sound and along the coast to the southward is usually darker colored. For this reason there is a strong demand for timothy grown in the irrigated districts around Ellensburg, Wash., and elsewhere in northeastern Washington and in northern Idaho, for export. As stated in another chapter, this timothy is baled in large quantities for the Alaskan and Philippine markets by the process of double compression. Where grown for home consumption, timothy is often mixed with red clover. The timothy may be sown in the fall and the clover in the spring, with oats; or the oats may be sown in the spring and the other two mixed and sown broadcast later. Sometimes the clover and timothy are sown together by means of combination drills. These machines have a separate feed box for the clover, which may drop the seed in the same holes with the timothy or sow it broadcast in front of the drill. On moister land and certain kinds of gravelly soil, alsike replaces the red clover in combination with timothy.

Timothy, either alone or in combination with clover, is frequently used for pasture. The method of establishing pasture employed by Mr. Wheeler, who owns a ranch near Reno, Nev., illustrates the possibilities in this direction, where water is available. Upon ordinary

sagebrush land, and without previous preparation, a mixture of alfalfa, timothy, red clover, and orchard grass were sown. Beyond irrigation, nothing further was done. The pasture, now 3 years old, is in excellent condition and consists chiefly of alfalfa and timothy. Under this treatment the sagebrush has gradually disappeared, though the dead stems may be found on the ground beneath the growth of grass. A meadow can be established in the same manner, but it is then necessary to level the land by some means, such as dragging the surface with heavy railroad iron drawn by several horses.

Grain Hay.

In central California and parts of the interior region, hay made from cereals is an important product. Grain hay is made from wheat, which is considered the best; from barley, and, to a less extent, from oats, though in many localities wild oat hay is commonly preserved. As previously stated, alfalfa is generally consumed on the farm, while grain hay supplies the city markets. For convenience it is usually baled. It is often the case that the price of the grain determines whether the crop shall be converted into hay or the grain be allowed to mature. For hay, the grain is cut when between the milk and the dough stages. It is preserved the same as other hay, but is allowed to cure in the bunch. It may then be stacked or, if possible, baled from the bunch. As there is little or no rain in the grain-hay region of California, there is little danger of injury from this cause by leaving the hay in the bunches.

On a large ranch near Lovelocks, Nev., an example was presented of the use of wheat to supplement the alfalfa crop. The latter had been seriously injured by the ravages of a variety of field mouse. Wheat was sown in the spring to fill up the places left bare from this cause and the mixed crop was converted into hay in the usual manner.

Redtop (*Agrostis alba*).

Redtop is frequently grown on wet meadows in the northern Rocky Mountain region and to some extent in other localities. It is not considered as valuable a grass as timothy, but from the fact that it thrives in moist land and can be sown upon native meadow, where under irrigation it resists fairly well the encroachments of rushes (wire grass), it is utilized both for hay and pasture. It is not usually grown alone, but with other grasses or clovers.

Awnless Brome Grass (*Bromus inermis*).

Awnless brome grass[a] has been grown for many years in Europe.

[a] For further information concerning this grass, see Circular No. 18, Division of Agrostology, U. S. Dept. of Agriculture, "Smooth Brome Grass."

where it is native. In recent years it has been tried in many parts of the United States with varying degrees of success. It has proven most successful in the semiarid regions of the Northwest from Kansas and North Dakota to Washington. It is especially adapted for those regions where the rainfall is insufficient to grow forage crops without irrigation and yet the conditions do not approach the aridity of the desert. Such regions are found in the eastern part of the Great Plains, plateaus in the Rocky Mountains, and the Palouse region of eastern Washington.

The seed may be sown broadcast in the spring, at the rate of about 20 pounds to the acre. The stand is usually thin the first year, but the second year it thickens up and forms a sod. In localities where winter wheat can be grown, brome grass can be sown in the fall. It is valuable for hay, but more especially for pasture. During midsummer the foliage dries up more or less, but gives good pasture in early spring and late fall. The second year it yields large crops of palatable hay, but thereafter it is better adapted for pasture than for hay. (See Pl. VII, fig. 2.)

Velvet Grass (*Holcus lanatus*).

This grass is common in the Pacific coast region along roadsides, in abandoned fields and other waste places, and also is found encroaching upon pasture land. It is a native of Europe, but has been introduced into many parts of the United States. Opinions differ as to its usefulness, some stigmatizing it as a vile weed, others referring to it as a valuable forage grass. It is not a very large yielder, but will thrive on poor soil where more valuable grasses fail. Hence in localities where the usual meadow and pasture grasses flourish the advent of velvet grass should be looked upon with disfavor, but on more sterile soil it furnishes a fair crop of forage where other grasses fail. It has been said that "velvet grass is a good grass for poor land, and a poor grass for good land." Velvet grass goes under the name of mesquite in many parts of the Northwest, but this name is more frequently applied to certain native grasses of the Southwest.

On sandy soils along the coast and on peaty soils that dry out in summer, velvet grass is perhaps the most profitable hay and pasture grass, because the better grasses do not succeed. Stock usually refuse to eat it at first until driven to do so by hunger, but they will soon acquire a taste for it, and it is exceedingly nutritious. Its worst faults are its low yield and lack of palatability.

Clovers.

Red clover (*Trifolium pratense*) is in common cultivation throughout the northern portion of the Rocky Mountain and upper Pacific coast regions and is rapidly coming into cultivation in the more moist

parts of eastern Washington and northern Idaho. Two crops of hay may be obtained, although in western Washington the approach of the rainy season may interfere with the second crop. The seed is usually sown in the spring, but on sandy land in western Washington it may be sown in the fall. As mentioned under the head of timothy, red clover is usually sown in combination with that plant.

Alsike clover (*T. hybridum*) is occasionally grown in the same localities where red clover thrives, but it is adapted to more moist land.

White clover (*T. repens*) is sometimes cultivated in combination with bluegrass in those localities where the latter thrives. Such pastures are frequently found in the mountain districts and along the upper coast region.

Forage Crops of Minor Importance.

The following forage plants are cultivated in sufficient abundance to receive attention. Some are already of importance in certain localities, and most of them should be cultivated over a wider area and given greater attention than is now the case:

Kentucky bluegrass (*Poa pratensis*).—In the mountain districts and the upper coast region bluegrass is used for pasture, usually in combination with white clover. Unless supplied with water during the summer months this grass gives little pasture during that season, but when the water supply is sufficient and properly distributed it yields abundantly. Upon the ranch of Mr. Wheeler, at Reno, Nev., there are several pastures of bluegrass and white clover which by means of irrigation are kept in good condition through the season. In some localities it is considered a pest on account of its tendency to drive out other grasses where the conditions are favorable for the growth of bluegrass. Mr. G. F. Chapman, of Evanston, Wyo., a prominent ranchman, states that it forms a thin, low mat which can not be utilized for hay, and is not as valuable for pasture as other grasses. This is usually true when the land is not irrigated, as it tends to dry up during dry periods to a greater degree than native grasses, but it starts early in the spring and remains green well into the fall.

Orchard grass (*Dactylis glomerata*.)—This well-known grass should be grown much more extensively than it is. It resists drought better than most of the tame grasses grown in the East, and can be used for pasture or hay. On account of the tendency to grow in bunches when sown alone, it is best, especially for meadow, to sow with some other grass. For this purpose meadow fescue is well adapted. The latter occupies the spaces between the bunches of orchard grass and thus forms a more even and continuous surface for the mower. Both bloom at about the same time, and both are capable of resisting drought to about the same extent.

CHEAT (*Bromus secalinus*).—In the eastern United States this grass is known as a bad weed in grain fields, but in the Willamette Valley of western Oregon it is used quite extensively for hay. It is common to see cheat sown along the draws or other low portions of grain fields. Mr. T. H. Cooper, a farmer near Corvallis who utilizes cheat in this way, sows the seed broadcast in the fall at the rate of 1 to 1½ bushels per acre. He cuts the hay when it is in the dough state, which is about the last of June. The yield of seed is about 40 bushels per acre, a bushel weighing 35 to 40 pounds. It is quite probable that cheat could be used for forage in other localities.

PERENNIAL RYE GRASS (*Lolium perenne*).—This is commonly grown in the Willamette Valley and in some other parts of Oregon and Washington and proves to be a good grass for pasture and hay. Although not considered as a grass for dry regions, the trials at the experiment stations of Kansas, Colorado, and Wyoming indicate that it stands well as a drought-resisting grass. The variety known as Italian rye grass scarcely differs from this, except in usually having the chaff or flowering glume provided with a bristle at the tip, and in growing somewhat taller.

RAPE (*Brassica napus*).—A plant to be recommended for pasture in the cooler parts of the Northwest is rape. It is now used to a limited extent in several localities, especially in the Rocky Mountain region. As a forage plant for sheep and as succulent forage for summer and fall, rape is to be highly recommended. It is not easily injured by frost and hence is available as fall feed. The seed should be sown in June or July, and rape may consequently be grown as a catch crop after grain or other early maturing crops. Where there is sufficient moisture the seed may be sown broadcast, but in the drier regions much better results are obtained by sowing in drills far enough apart to permit of cultivation. In eight to ten weeks from sowing it is ready for use, and sheep can be turned into the field to pasture off the succulent growth. It is also an excellent feed for cattle, but they are likely to waste more by trampling than smaller stock.

FIELD PEAS (*Pisum arvense*).—This leguminous plant is adapted for use as a forage plant in the northern portion of the Northwest and farther south in the mountains. At present it seems to be grown to a comparatively limited extent, but it is worthy of culture to a much greater degree. Canada field peas can scarcely compete with alfalfa in the regions where the latter can be grown; but where alfalfa is not successful on account of the cooler climate the peas are an excellent substitute, in that they are rich in protein, and hence have a high feeding value. It is best to sow them with grain—oats, wheat, or barley being used for the combination—at the rate of 1 to 1½ bushels of peas to an equal quantity of grain. The crop can be cut for hay or used for pasture.

VETCHES.—In the Willamette Valley, Oregon, spring vetch (*Vicia sativa*) is commonly grown for hay and annual pasture. Mr. T. H. Cooper, of Corvallis, uses vetch for his silo, after which he uses green corn. He sows the seed in the fall with wheat or oats, 2 bushels of the mixture containing about a peck of grain. The crop is cut in June. Spring vetch is cultivated here and there in the cooler parts of the Northwest, but the crop as a whole is very insignificant when compared with the staple forage crops of the region. The plant is a legume, and can gather nitrogen from the air in a manner similar to clover and alfalfa. Hence it furnishes forage rich in protein and at the same time acts as a soil renovator. While spring vetch can not be successfully grown over much of the area under consideration on account of the heat and drought, yet it is to be highly recommended for those localities having a cool, moist growing season. In the upper coast region it can be sown in the fall. In the mountain regions it should be sown in spring. It is best to sow with grain, as the latter tends to hold the vetch upright, and it can thus be handled for hay more easily, and also because the grain mixture produces a more evenly balanced feed. After the mixture of grain and vetch is cut, a second crop of vetch will usually appear, which can be saved for seed.

Hairy or sand vetch[a] (*Vicia villosa*) has been tried to a limited extent, but the results over most of the region described are not promising. It thrives, however, in the Palouse region and tends to become a weed in wheat fields.

BALING HAY.

As in other parts of the United States, it is customary to bale hay for convenience in transportation. Most of the hay consumed in the larger cities is of this kind. The baled hay upon the markets of the Northwest is for the most part restricted to alfalfa, clover, timothy, grain, and wild or native hay. In San Francisco and other cities of California, grain hay takes the lead, while at Seattle and the cities of the Sound, timothy is most used, the kind depending in part on the availability and in part on the demand of the market. Alfalfa is, in many cases, as available as timothy, or more so; but the latter is used in the cities in preference because it is believed to be more suitable for horses. In fact, timothy hay is taken as the standard upon the city markets. The type of press used at San Jose, Cal., is shown in Pl. VII, fig. 1.

The item of freight often enters greatly into the market price of baled hay. For example, during the summer of 1901, grain hay was worth $8 per ton at Raymond, a town upon the railroad, while at Yosemite the freight charges brought it up to $40 per ton, and at the same time the

[a] For further information upon the vetches, see Circular No. 6, Division of Agrostology, U. S. Dept. of Agriculture, "The Cultivated Vetches."

price of hay at Nome, in Alaska, was 7 cents per pound, even when double compressed.

Baled hay for export to Alaska, Hawaii, the Philippines, and other trans-oceanic points is compressed by the process known as "double compression." By means of powerful machines operated by electricity or hydraulic power, the hay, obtained by loosening ordinary baled hay, is compressed into square or cylindrical packages smaller and more compact than the ordinary bale. The hydraulic presses used for making the so-called round bales are similar to those used for making the cylindrical bales of cotton. The measurements of the different types of double-compressed bales are about as follows:

Ordinary square bale, 15 by 18 by 38 inches; weight, 160 pounds.

Square bale for Alaskan trade, 14 by 18 by 26 inches; weight, 100 pounds.

Round bale, 2 feet in diameter, 24 inches long; weight, 145 pounds, or 36 inches long, weight, 260 pounds.

The saving of space in transit may best be understood by comparing the weight and cubic contents of baled and compressed hay. The ordinary baled hay occupies 140 to 160 cubic feet per ton; the square double-compressed, 85 feet per ton; the round bales, 55 feet per ton.

The hay used for this process is almost exclusively timothy. The firm of Lilly, Bogardus & Company, Seattle, Wash., from whom much of the information concerning double-compressed bales was obtained, states that the timothy from the Ellensburg district, Wash., is much preferred on account of the fresh green color. A good quality is also obtained from the Spokane and Cœur d'Alene districts. On account of the damp weather, timothy from west Washington is not so satisfactory in appearance. There is some demand for clover hay in Alaska, and much grain hay is shipped to Honolulu. There is also a small but increasing demand for alfalfa hay for export.

DESCRIPTION OF PLATES.

PLATE I. Fig. 1.—Mast and boom stacker, with six-tined Jackson fork. The mast is held in place by guy ropes from the top. Leading to the right may be seen the rope to which is attached a team of horses. The base of the derrick is in the form of sled runners, so that the whole may be drawn along the stack by attaching a team. Fig. 2.—A cable derrick, provided with a grapple fork. The cable is supported by poles at the ends, and these in turn by guy ropes.

PLATE II. Fig. 1.—A derrick stacker, with six-tined Jackson or California fork. The derrick is substantial, and guy ropes are not necessary. Stakes driven into the ground around the base hold the derrick in place. Fig. 2.—The same derrick, showing details. It will be observed that from the peculiar attachment of the ropes, the hay is swung over the stack while it is being lifted from the wagon.

PLATE III. Types of derrick stackers. Fig. 1.—Derrick built on wheels and symmetrically braced. Fig. 2.—Derrick with revolving pole. In both forms the central pole rotates in sockets. The ropes are not attached to this derrick.

PLATE IV. Fig. 1.—A common type of hayrack. Fig. 2.—A pole stacker, with four-tined Jackson fork. The angle of the pole is regulated by a short beam. This is often replaced by a chain or rope. The derrick leans toward the stack sufficiently to swing the fork load of hay into position, when it is elevated.

PLATE V.—Types of racks in common use for feeding alfalfa to cattle. Fig. 1.—Lattice rack. Fig. 2.—Box rack.

PLATE VI.—Types of racks for feeding alfalfa to sheep. These racks are longer than those intended for cattle. Fig. 1.—Lattice rack. Fig. 2.—Box rack.

PLATE VII. Fig. 1.—Hay press, for baling grain hay, San José, Cal. Five men and three horses are employed; one man and horse drag the hay from the stack to the baler, with a four-tined Jackson fork; one man drives a team attached to the horse-power; two men pitch the hay into the baler; one man works the press and weighs the bales. Average time, three minutes to the bale. Weight of bales, about 210 pounds. Bales tied with rope. Fig. 2.—Field of brome grass at the Kansas Experiment Station, Manhattan, Kans. A seven-year-old boy stands in the grass.

FIG. 1.—MAST AND BOOM STACKER, WITH JACKSON FORK.

FIG. 2.—CABLE DERRICK, WITH GRAPPLE FORK.

FIG. 1.—DERRICK STACKER, WITH JACKSON FORK.

FIG. 2.—DERRICK STACKER, SHOWING DETAILS.

Bul. 31, Bureau of Plant Industry, U. S. Dept. of Agriculture.

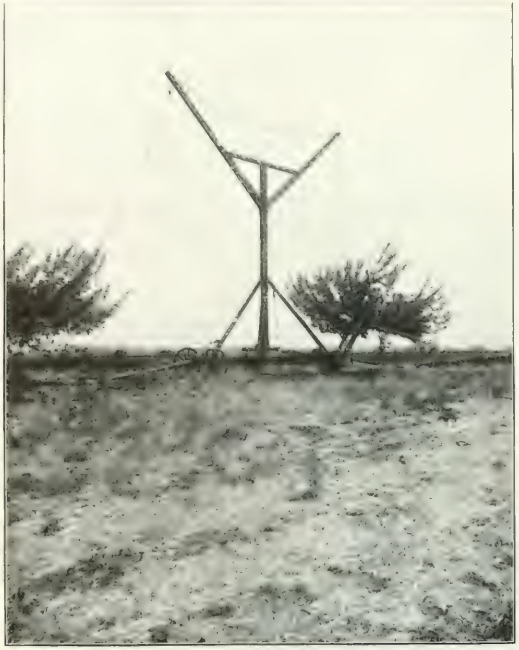

FIG. 1.—DERRICK MOUNTED ON WHEELS.

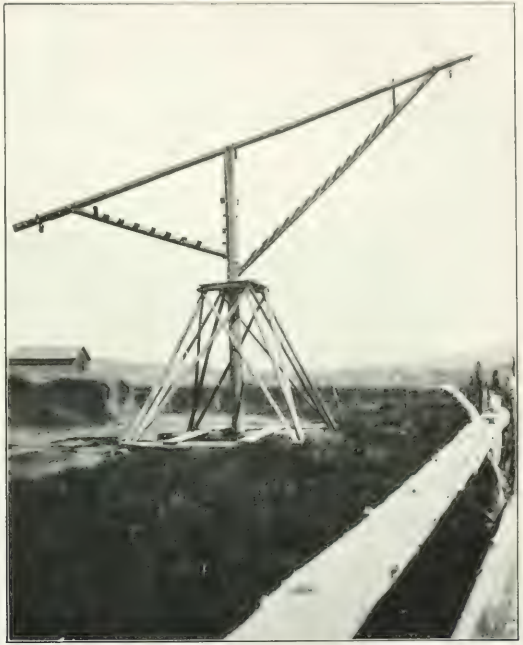

FIG. 2.—DERRICK WITH REVOLVING POLE.

FIG. 1.—A COMMON TYPE OF HAYRACK

FIG. 2.—POLE STACKER, WITH JACKSON FORK.

FIG. 1.—LATTICE RACK FOR FEEDING ALFALFA TO CATTLE.

FIG. 2.—BOX RACK FOR FEEDING ALFALFA TO CATTLE.

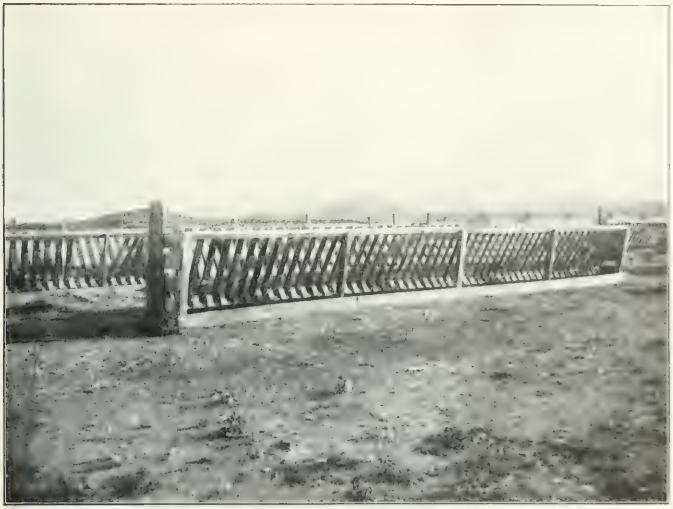

FIG. 1.—LATTICE RACK FOR FEEDING ALFALFA TO SHEEP.

FIG. 2.—BOX RACK FOR FEEDING ALFALFA TO SHEEP.

FIG. 1.—BALING GRAIN HAY, SAN JOSE, CAL.

FIG. 2.—BROME GRASS AT THE KANSAS EXPERIMENT STATION.

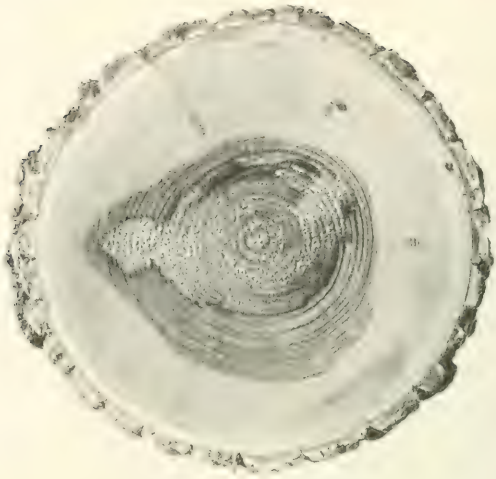

FIG. 1.—EARLY STAGE OF DISEASE.

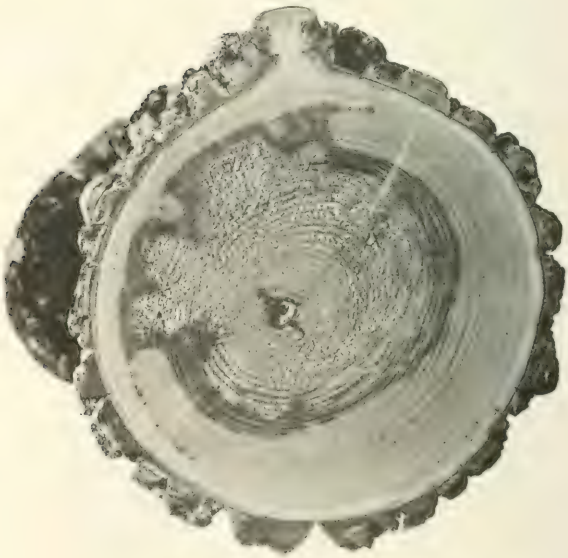

FIG. 2.—LATER STAGE OF DECAY.

TRUNKS OF YOUNG WHITE ASH TREES, SHOWING EARLY AND LATER STAGES OF DISEASE.

HELIOTYPE CO., BOSTON.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN No. 32.

B. T. GALLOWAY, *Chief of Bureau.*

A DISEASE OF THE WHITE ASH CAUSED BY POLYPORUS FRAXINOPHILUS.

BY

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ISSUED FEBRUARY 28, 1903.

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1903.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., October 24, 1902.

Sir: I have the honor to transmit herewith, and to recommend for publication as Bulletin No. 32 of the series of this Bureau, the accompanying technical paper entitled "A Disease of the White Ash Caused by Polyporus Fraxinophilus."

This paper was prepared by Dr. Hermann von Schrenk, Special Agent in Charge of the Mississippi Valley Laboratory, Vegetable Pathological and Physiological Investigations, and it has been submitted by the Pathologist and Physiologist with a view to publication.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The accompanying paper treats of a disease of the white ash caused by *Polyporus fraxinophilus*, concerning which a number of inquiries have lately been made. It has been carefully studied by Dr. Hermann von Schrenk, who has charge of the Mississippi Valley Laboratory of Vegetable Pathological and Physiological Investigations, located at St. Louis. This disease is prevalent in the Mississippi Valley, which is the western limit of the white ash, and is particularly severe in Missouri, Nebraska, and eastern Kansas, fully 90 per cent of the trees in some localities being affected. The ash is extensively grown in parks and grounds, where the white rot does considerable damage. Its mode of growth and entrance into the tree may be taken as a type for many wound parasites destroying ornamental and shade trees, and it is believed that a knowledge of its life history and the methods to be used for combating it will prove of considerable benefit at this time both to foresters and others interested in the preservation of trees.

ALBERT F. WOODS,
Pathologist and Physiologist.

OFFICE OF THE PATHOLOGIST AND PHYSIOLOGIST.
Washington, D. C., October 17, 1902.

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A DISEASE OF THE WHITE ASH CAUSED BY POLYPORUS FRAXINOPHILUS.

INTRODUCTION.

The white ash is attacked by a number of fungus parasites, which grow on the living leaves and do more or less injury. *Aecidium fraxini* Sch., the orange rust, is perhaps the one best known, as it grows on almost all species of ash, even the introduced forms. It occurs with varying frequency in successive years, and, so far as known, has appeared in epidemic form but once (1885). Among the fungi which grow as parasites on leaves are several species of *Gloeosporium* and *Sphaeropsis*, as well as *Septoria fraxini* and *Phyllosticta fraxini* Ell. & Mart. *Sphaeronema spina* Berk. & Rav. grows on young twigs, and kills a good many now and then.

The fungi mentioned above, to which several others might be added, rarely appear in sufficient numbers to do very much harm to the trees affected.

WHITE ROT.

There is one fungus, *Polyporus fraxinophilus* Pk., which grows in the heartwood of the trunk and branches of the white ash. This fungus changes the hard wood of the ash into a soft, pulpy, yellowish mass (Pl. I), making it unfit for lumber purposes. Diseased trees are ultimately blown down by windstorms. In regions where this disease is common the ash never grows to be a very large or very old tree. During the last year numerous inquiries have been made as to the causes of the white rot and how it could be prevented. In Forest Park, St. Louis, nearly all the white ash trees were diseased, and many were blown over by the wind.

A diseased tree is readily recognized by the large, conspicuously colored sporophores, which usually occur in considerable numbers, one or more at every branch stub. *Polyporus fraxinophilus* has been studied by the writer, particularly in Missouri, where it occurs in great numbers on the ash. It has been found elsewhere in the United States and has been reported from as far east as Albany County, N. Y.

[a] Peck, C. H. Thirty-fifth Report, New York State Museum.

GEOGRAPHICAL DISTRIBUTION.

The distribution of this fungus is very interesting when considered with reference to its host. The white ash, as indicated on the accompanying map (fig. 1), is found throughout the entire eastern United States, growing as far westward as eastern Kansas and Nebraska. Judging from the very meager data now at hand, it seems that *Polyporus fraxinophilus* is most common near the western limit of the distribution of the white ash. It is very common in parts of Missouri, Kansas, Indian Territory, and Iowa. In the eastern United States, so far as the writer was able to ascertain, it is comparatively rare.

Near its western limit *Fraxinus americana* is at best a tree of medium size and development. On the dry limestone hills west of the Missis-

FIG. 1.—Map showing distribution of Fraxinus americana L.

sippi it grows slowly, as is evident from the sections shown on Pl. I, which are three-fourths natural size. In this region *Polyporus fraxinophilus* will be found on 90 per cent of the standing trees. The diseased trees were counted in two circumscribed localities, in neither of which was a tree more than 5 inches in diameter found to be sound.

The fact that in a given locality so high a percentage of the individuals of a species are diseased at a relatively early age may be explained by the greater virulence of the disease-causing factor or by the greater susceptibility of the individual; in this case, probably the latter. That this disease does not directly affect the living parts of the tree has no weight, for in the long run it affects it indirectly by undermining its support.

SUSCEPTIBILITY TO THIS DISEASE.

The question of the relative susceptibility of individual plants to a disease is a most interesting and at the same time a most obscure and difficult one to discuss. In the present instance it would seem that there might be some relation between the greater susceptibility on the part of the ash near its western limit and its generally weaker development at this limit. It will be an interesting point to determine, for instance, whether the rate with which branch wounds or stubs heal in Ohio and Pennsylvania is greater than in Missouri and Kansas. That the rate of growth is slower in the Western States we know.

Polyporus fraxinophilus has been reported as growing on living trees of *Fraxinus viridis* in Rooks County, Kans.[a]

METHOD OF ATTACK.

Polyporus fraxinophilus attacks ash trees of all ages, usually, however, those more than 7 inches in diameter. The fungus begins its growth in a wound, or more often in a dead branch. It would perhaps be more correct to say that the fungus gains entrance into the tree at the point where the callus touches the branch stub. The branches of the ash are usually inclined upward at a considerable angle, and the callus leaves a groove between its outer surface and the branch stub in which water can collect. From sections of old branch stubs it appears that the earliest signs of fungus action are found in the outer parts of the dead stub close to this groove. The fungus grows down toward the center of the tree in the outer layers, and from these spreads to the main trunk up and down and laterally. It is quite usual to find a tree infected at two or more separate points. In a region where the sporophores are common and where each tree has many dead branches this is not at all surprising.

DESCRIPTION OF DISEASED WOOD.

The wood of the ash is uniformly straw yellow in color and shows little difference in tint between heart and sapwood. A gradual darkening of the wood near the center of the tree is the first indication of the presence of the fungus mycelium (Pl. I). In an irregular patch the wood looks as if stained, at first a very light brown, later on a darker brown. The broad bands of summer wood show this change in color most conspicuously. The next stage in the disease is marked by a bleaching of the color in the spring duct layers; these gradually turn back to the original straw color and then turn white in spots. The white color becomes more marked until the entire spring wood is white. It has a disintegrated appearance by this time, and shortly afterwards all the fibers fall apart. The dense bands of summer wood

[a] Ellis & Everhart, N. A. Fungi, No. 3302.

change more slowly. This gives rise to a banded appearance near the edge of the diseased area, more pronounced in some places than in others (see the lower part of Pl. I, fig. 2). Ultimately the whole wood ring turns into a loosely connected mass of fibers.

When the tree is first attacked it appears as if the changes described take place simultaneously over a large area (3 square inches in the tree shown in Pl. I, fig. 2), and that thereafter the change from sound to decayed wood goes on more slowly. This is the case in diseases of other trees, and is possibly accounted for by the fact that at first no products of metabolism interfere with the growth of the fungus, while later on these may retard growth to some extent.

The completely rotted wood is straw colored, very soft and nonresistent, and readily absorbs water. The disintegrating changes are by no means uniform, as a glance at Pl. I will show. The diseased areas have very irregular shapes; sometimes they involve the whole trunk, at other times only one side, depending somewhat on the point of infection and the shape of the trunk. In the trunk shown in the lower figure on Pl. I the fungus was growing in the seventh ring from the bark.

THE SPOROPHORE.

The sporophores of *Polyporus fraxinophilus* appear around the base of branch stubs, or in wounds, very soon after the original infection (Pl. II). With some trees—for instance, *Pinus echinata* attacked by *Trametes pini*—it appears that a good deal of wood is destroyed before any fruiting bodies of the fungus form. With the ash, fruiting bodies make their appearance when the wood shows signs of having decayed only a very short distance from the point of infection. In one tree, where the sporophore was developing at a branch stub, the heartwood was actually rotted for a distance of only 4 inches on either side of the base of the branch, while the characteristic discoloration extended for a foot in both directions from the stub. When the dead branch is a large one, small white knobs grow out at several points near its base (Pl. II, fig. 2), often as many as ten or a dozen. These knobs are almost white, very smooth, and adapt themselves to the irregularities of the rough bark. When the branch extends out horizontally, the sporophore frequently appears to be hanging from the under side of the branch (Pl. II, fig. 1). As the sporophores grow older they extend downward on the bark; in other words, become decurrent behind.

The mature sporophore is nearly triangular in cross section. Although fairly regular in form, there are many sporophores which are compound, i. e., composed of several superincumbent shelves or several shelves joined laterally. It has a broad rounded edge, which at first is white and gradually turns darker until it becomes somewhat straw colored. The older portions of the upper surface are dark brown or black, and are very hard and woody.

The youngest part grows out over the older portions, which makes old sporophores look somewhat sulcate. The main body of the mature sporophore is very hard and woody. It is obscurely zoned and pale brown or rust color. The pores are very regularly stratose. They are short and of regular cross section. The youngest ones are white, the older ones red brown. They extend from the point where the sporophore touches the bark almost to the edge of the sporophore.

There is some question as to what name ought to be given to this fungus. Two species of *Polyporus* growing on the ash have been described—*Polyporus fraxineus* (Bull.) Fr. and *Polyporus fraxinophilus* Pk. The European fungus is described by Bulliard[a] and Fries[b] as sessile, corky-woody, azonate, at first smooth, then concentrically sulcate, at first white, then red brown or brown, pale inside, pores minute, short, at first white, then red brown or rust color. This description accords fairly well with the specimens distributed in Thümen's Myc. Univ., No. 806, except that these specimens can hardly be called "woody." In 1881 Professor Peck described a fungus, *Polyporus fraxinophilus*, growing on ash trees in Albany County, N. Y., as follows:[c]

> Pileus sessile, thick, corky, subtriquetrous, narrow, somewhat decurrent behind, the first year whitish, with a minute whitish tomentum or hairiness, then gray, finally blackish, in old specimens concentrically sulcate, rimose, the substance within obscurely zoned, at first whitish, then isabelline or pale tawny, the margin obtuse; pores stratose, plane or subconvex, small, nearly equal, subrotund, the dissepiments obtuse, entire, whitish; spores white, broadly elliptical, .0003–.00035 inch long, .00025–.0003 inch broad. Pileus 2–4 inches long, 1–1.5 inches broad.

A comparison of the two descriptions will show that they are almost the same, differing in small details. Anyone who has tried to separate the species of this variable genus will have become impressed with the inadequacy of many of the older descriptions, and in the present instance it becomes a matter of extreme difficulty to determine whether the descriptions of Bulliard and Fries fit the American fungus. In most respects the latter agrees with the descriptions, except in the red-brown pores. The European specimens seen have red-brown pores. On the other hand, there can be no doubt as to the identity of the ash fungus with *Polyporus fraxinophilus* Pk. The decurrent pileus, at first with a whitish tomentum, later gray, and finally black, can not be mistaken for any other. In view of the fact that the only European specimens of *Polyporus fraxineus* available do not agree with the present fungus it is deemed best to retain the name given by Professor Peck for the present. It may be found necessary to make it a synonym of *Polyporus fraxineus* after a further comparison with European material.

[a] Bulliard, M. Hist. des Champignons de la France, 1:341, 1741.
[b] Fries, Elias. Systema Myc., 1:421; Rabenhorst's Kryptogamenflora, 1:421, 1884.
[c] Peck, C. H. Thirty-Fifth Report, New York State Museum, 1881, p. 136.

The fungus under discussion is one of the most distinct forms of the *Fomes* type of *Polyporus*, and considering the great variability of form of many species of this genus it can be said to be remarkably constant in most of its characters.

MICROSCOPIC CHANGES IN THE WOOD.

The minute changes which the wood cells undergo are marked by great distinctness and regularity. The wood of the ash forming the bulk of the trunk serves as a repository for large quantities of starch. Even in trees which are 75 to 100 years old one will find starch almost at the center. In the ash the starch occurs in the form of small grains (Pl. IV, fig. 6), filling the cells of the medullary rays and wood parenchyma. Fig. 1, Pl. III, represents a cross section of wood (cut in March), stained with iodine. The medullary rays appear almost as black lines.

One of the first changes noticeable in the wood when attacked by the ash fungus is in connection with this starch. The region where the starch changes is just outside of the dark line seen in Pl. I. The large grains (Pl. IV, fig. 6) appear to break up into numerous smaller ones (Pl. IV, fig. 7), and finally even these disappear. The change is a very rapid one, and transition stages are very rare. No such regular gradual dissolution of the grains occurs as is described by Hartig as taking place in oak wood attacked by *Polyporus sulphureus* and *Polyporus igniarius*. When stained with iodine one finds large grains now and then, with channels through them (Pl. IV, fig. 6), or more frequently some which look as if the center had been dissolved out. In several instances grains were found which stained brown with iodine at the edges. This brown color then gradually passed in toward the center of the grain.

No hyphæ are present in the wood where the starch is breaking up. This would indicate that a diastatic enzyme given off by the mycelium precedes the latter for some distance. The first hyphæ are generally several rings farther toward the middle of the trunk. The even extent of the solution strengthens this supposition, for in a limited area of one wood ring one and the same stage of dissolution is found at about the same distance from the point where the fungus begins its growth. After the disappearance of the smallest grains the cells formerly filled with starch appear empty for several cell rows inward. Shortly after the disappearance of the starch they become filled with a bright-colored substance, which is probably liquid at first and hardens after infiltration into the cells (Pl. IV, fig. 2). This substance, which is very soluble in alkalis, is probably some humus compound which must be regarded as a decomposition product. It is distributed throughout the medullary rays and the woody parenchyma, occupying almost the identical cells which had harbored the starch. This will

readily be comprehended by a comparison of Pl. III, figs. 1 and 2. Fig. 2 is from a photograph of an unstained section taken from the region of brown wood at the outermost edge.

It is rather difficult to determine the origin of this decomposition product. It is possibly the last product of a change in the starch grains, possibly also a substance derived from wood cells farther inward, which infiltrates into the medullary ray cells and wood parenchyma in advance of the fungus hyphæ. The latter is the probable explanation, for one finds the humus compound in the summer wood cells, which had very little starch originally. The humus compound appears to form in many of the wood cells, however, as a product of the walls. Figs. 4 and 5 of Pl. IV show various stages of this change. The cells *a* are sound wood cells, which have very thick walls and a very small lumen. The walls of cells marked *b* are very much thinner, and at these points they are coated with the humus compound. Such walls when stained with phloroglucin show no very sharp dividing line between the yellow humus compound and the apparently sound lignified wall. Cell *c* is completely filled with the humus mass. This evidence that the wall actually changes into the yellow mass is not very conclusive. The humus compound does not seem to be formed from the walls of the medullary ray cells, where it is found ultimately, for no signs of change are evident in the walls of these cells. The localized distribution of the humus substance is very striking. It is always absent from the wood cells of the spring wood (Pl. III, fig. 2) and from the large vessels. In the cells it appears to be as a solid mass, sometimes completely filling the lumen (Pl. IV, figs. 2 and 5), or in globules or plates adhering to the walls (Pl. IV, fig. 2). It is this substance which gives the brown color to the early stage of diseased wood.

The next stage in the dissolution of the wood cells takes place abruptly, and is rapid after it has once set in. The hyphæ of the fungus first evident in the medullary rays spread through the wood of both the spring and summer bands, branching in all directions. They give off an enzyme which attacks the inner parts of the wood cells, extracting the lignin. A transverse section of wood in this stage (Pl. IV, fig. 1) stained with phloroglucin presents a most striking picture. Here and there, in irregular groups and in all stages, one finds wood cells from which the hadromal has been removed: the extracted parts remain white and stand out in sharp contrast to the unaffected parts of the walls. In the figure the unaffected parts are shaded. The white parts represent delignified walls. The middle lamella is dissolved last and then the individual cells fall apart. When this takes place throughout larger areas, for instance, one or more wood rings become separated from one another, and this gives rise to the plates spoken of above. The white areas which are evident in the figures on Pl. I represent wood thus destroyed. The individual fibers

remain intact for some time, and are then gradually dissolved. In the oldest parts of diseased wood they are no longer present.

Wood partially destroyed in the manner just mentioned was stained with potassium permanganate, HCl and NH_4OH, according to the method recently described by Maule.[a]

A dilute solution of the permanganate is allowed to act on the wood for a minute. The wood is then treated with strong HCl until no color is visible. A drop of ammonia is then added. The lignified walls stain a deep red, which in many respects defines the various parts of the walls more sharply than the phloroglucin reaction. The parts (Pl. IV, fig. 1), which do not stain with phloroglucin do not stain with the permanganate. The contrasting color between the lignified and delignified parts is even sharper. Maule claims that the permanganate reacted with an ether compound in the walls even after the removal of Czapek's hadromal. In the "delignified" wood cells of the ash even this compound (if there be a separate compound which reacts with the permanganate) is therefore absent.

In the ash wood the white fibers are not pure cellulose. The same is true of many similar fibers from oak wood destroyed by species of *Hydnum*, or *Polyporus igniarius*, and probably of other white fibers resulting from fungus action on wood. With chloriodide of zinc, the best cellulose reagent we have, these fibers stain a yellow brown, not blue. This would indicate that the change in the wall is not the same as in many of the conifers, where the so-called lignin is destroyed, leaving a comparatively pure cellulose, as determined by staining reaction and macrochemical analysis. This subject is simply referred to in this connection, as it will form the subject of a separate paper.

The change to an impure cellulose takes place locally, and generally very early in the course of the destructive action of the fungus. The mass of wood destroyed changes somewhat differently. The first changes noticeable are in the medullary rays and immediately adjoining cells. Very fine fungus hyphæ invade these cells, and shortly after the middle lamellæ disappear. Small cavities occur in thicker parts of this layer, i. e., where several cells touch (Pl. IV, fig. 3, *a*), and these increase in size (*c*), spreading laterally, until two or more join. Ultimately the individual cells become entirely isolated. The wood cells proper are gradually destroyed from within outward, the middle lamellæ remaining longest. The change from perfectly sound wood to wood entirely dissolved is a very abrupt one (Pl. IV, fig. 8). The hyphæ invade a cell and dissolve the wall. So rapid is this that no intermediate changes can be found. A piece of completely rotted wood, such as occurs in the center of a diseased trunk (Pl. I), is represented in Pl. IV, fig. 8. A more resistant piece of summer wood is

[a] Maule, C. Das Verhalten verholzter Zellmembranen gegen Kalium permanganat, eine Holzreaction neuer Art. (Beiträge zur wissenschaftlichen Botanik, Vol. IV. Stuttgart, 1901.) (Reviewed in Bot. Cent., 89. 328, 1902.)

shown at one side. It is surrounded by an intricate mass of hyphæ, in which pieces of undissolved wood are held in much the relative position which they occupied in the sound wood. It will be seen that the wood is practically destroyed entirely. The mass of fungus hyphæ gives a soft, leathery, yielding consistency to the rotted material.

The young hyphæ are exceedingly fine, so much so that it requires a strong immersion lens to detect them. They are perfectly colorless, and remain so when older. Clamp connection occurs frequently.

GROWTH OF THE FUNGUS IN DEAD WOOD.

The mycelium of the fungus grows only in living trunks, so far as could be ascertained. It will grow out from infected wood when the latter is kept in a moist place, but only to a very small extent. A number of pieces of diseased ash trunks, each about a foot long, were placed in the mushroom cellar of the Missouri Botanical Garden, some with the cut surface in contact with the soil, others exposed to the moist air. In order to test whether dead wood could be infected, several healthy pieces of ash trunks, recently cut and of about the same diameter as the diseased pieces, were placed in contact with the smoothed end surfaces of the diseased pieces. After two or three days the hyphæ in nearly all the pieces began to grow out from the diseased areas (Pl. V), both from the brown areas and from the parts entirely decayed. This indicates that the fungus is equally active all through the diseased parts. In the pieces where the cut surfaces were exposed to the moist soil or air the hyphæ grew for some weeks, making a thick, tough felt. They gradually ceased growing after about three weeks. The sound ash trunks were firmly united to the diseased ones after three days, and after a week the fungus had so thoroughly united the two pieces that they could not be pulled apart, using a moderate amount of force. After three months the healthy pieces were examined. The hyphæ of the fungus had grown into the wood for a very short distance only. They had effected practically no change. A hard cushion of mycelium had formed between the two pieces, and this was turning brown and had evidently ceased growing. These tests show that under the conditions of temperature and moisture which permit of vigorous growth of several of the wood-destroying fungi growing on dead wood the mycelium of the ash fungus will not grow for any length of time. The sound wood placed in contact with the diseased wood was full of starch at the time, so it could not have been lack of food which prevented the growth of the hyphæ. A piece was removed from a sporophore immediately after it was brought in from the woods. The sporophore remained attached to a section of the trunk about a foot long. For several weeks hyphæ grew out from the injured surface, making a new rounded edge, doing so almost as rapidly as in the natural state.

REMEDIES.

The white ash is becoming more valuable as a lumber tree, and it is being grown extensively as an ornamental tree in parks and grounds. In limited areas it will pay to adopt measures which will tend to prevent the disease described in the foregoing pages, or at least to recognize diseased trees and use them for lumber, so as to save the parts still sound. A disease such as the white rot of the ash is a difficult one to combat after a tree is once badly diseased, for the fungus grows in the interior of the trunk, where it can not be reached. Trees which grow in forest tracts should be cut down when badly diseased, so as to prevent the spread of fungus spores. That a persistent cutting out of diseased trees will in a comparatively short period reduce the number of newly infected trees has been demonstrated repeatedly in European forests, where it is now often impossible to find many well-known forms of disease which were formerly comparatively common.

In parks and grounds diseased trees, when they appear healthy otherwise, need not necessarily be cut down, for the trees may remain alive and vigorous even when the heartwood is partially decayed. The only danger is that trees weakened in that way are liable to be broken off by windstorms. A diseased tree can be recognized as soon as the white punks or sporophores appear at a knot hole. As soon as a punk appears it can be cut out, and some of the diseased wood with it. The hole should then be filled with tar oil and left open for a time. Tar oil should be added from time to time, as a good deal will soak into the decayed wood, and thereby arrest the further growth of the fungus to some extent. If the hole made by removing the punk is a large one it should be covered with tar paper, so that no opening is left for water or dust to enter.

A sure method of combating this disease is by a careful system of pruning and the coating of all wounds with an antiseptic substance. Vigorously growing ash trees heal wounds rapidly, and after three or four years any ordinary-sized wound will be completely occluded. In treating trees planted in parks or gardens the pruning had best be done in the winter. Care should be taken to cut all branches as close to the trunk as possible, and after trimming the ragged edges of a cut the whole surface should be coated. Ordinary gas tar is the best substance for this purpose. If too hard it should be heated so as to be fairly liquid and then applied with a brush. The gas tar, especially when warm, penetrates for a considerable distance into the wood and prevents the development of the ash fungus. It forms an air-tight and water-tight cover which is not destroyed by weathering, and which at the same time is objectionable to insects.

Where the coating of wounds is carried on with care it will be entirely practicable and possible to prevent this ash disease.

PLATES.

DESCRIPTION OF PLATES.

PLATE I. (Frontispiece.) Sections of living white ash trees (*Fraxinus americana*) attacked by *Polyporus fraxinophilus* Pk. The upper figure shows an early stage; the lower, a later stage of the decaying process.

PLATE II. Fig. 1.—Fruiting body of *Polyporus fraxinophilus* Pk. growing out from a dead branch. This is a rather exceptional form of sporophore, which is found only on branches. Fig. 2.—Two young sporophores of *Polyporus fraxinophilus* Pk. growing on living ash. Fig. 3.—An old sporophore of *Polyporus fraxinophilus* Pk. growing on living ash.

PLATE III. Fig. 1.—Transection of healthy ash wood, stained with iodine so as to show the distribution of starch in the medullary ray cells and in the wood parenchyma surrounding the large ducts. This section is made just outside the dark line dividing sound from diseased wood (see Pl. I). Fig. 2.—Transection of diseased ash wood, not stained, showing the distribution of a humus compound in the medullary ray cells and in the wood parenchyma surrounding the large ducts. This section is made just inside the dark line dividing sound from diseased wood (see Pl. I).

PLATE IV. 1.—Transection of ash wood, showing one form of change in the wood cells caused by the fungus hyphæ. The darkly shaded parts are sound wood cells. The white parts are wood parts which do not stain with phloroglucin. (Magnification same as for fig. 2.) 2.—Transection of medullary ray from the brown wood layer, showing how the cells become filled with a brown humus compound, here shown by the dotted areas. In two cells the dry compound has cracked. 3.—A medullary ray, showing a later stage of fungus attack. The middle lamellæ are dissolved out, separating the individual cells from one another. Note the absence of the humus compound. (Magnification same as for fig. 2.) 4 and 5.—Transection of wood cells (highly magnified), showing various stages of change of wood into a brown humus compound. Note the great thickness of walls of neighboring sound cells. The humus compound is shown by the shaded parts. 6.—Starch grains from medullary ray cell. Normal grains and several grains showing how grains are now and then dissolved. The short line equals 10μ. 7.—Starch grains from diseased wood, showing how the large grains are broken up into smaller ones. (Magnification same as for fig. 6.) 8.—Transection from entirely rotted wood. The sound wood cells at one side belong to a small piece of more resistant wood. (Magnification same as for fig. 2.)

PLATE V. Cross section of diseased trunk of the white ash kept in a moist place for several weeks. The fungus hyphæ have grown out from the diseased wood, forming a white felt.

FIG. 1.—FRUITING BODY OF POLYPORUS FRAXINOPHI

FRUITING BODIES OF

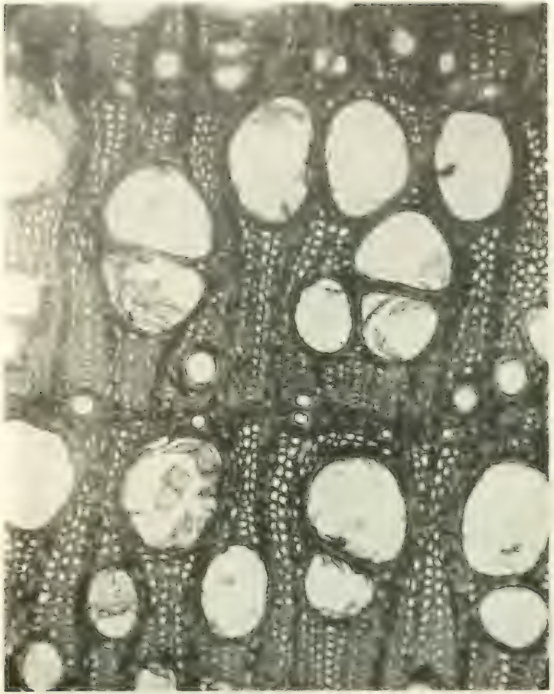
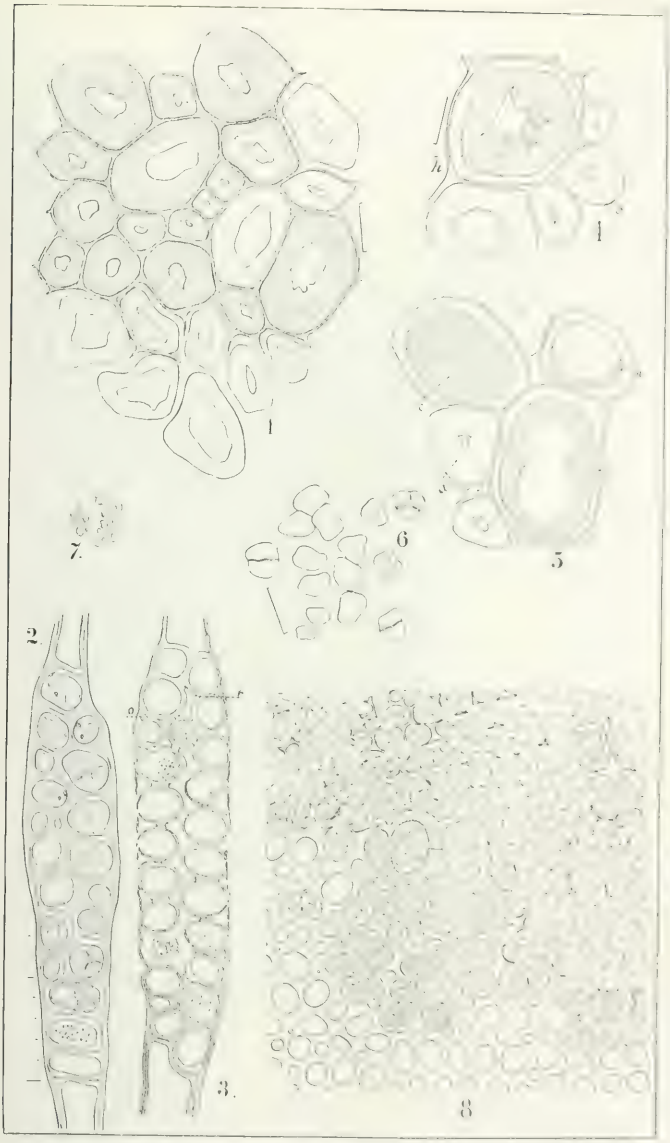


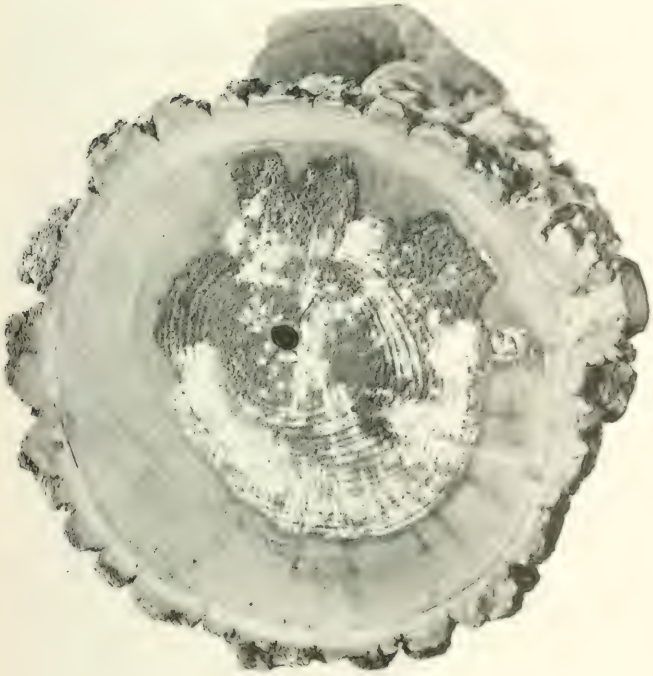
FIG. 1.—HEALTHY ASH WOOD SHOWING STARCH IN THE MEDULLARY RAYS.

FIG. 2.—DISEASED ASH WOOD SHOWING HUMUS COMPOUND.



DISEASE CAUSED BY POLYPORUS FRAXINOPHILUS.

1, Transection of ash wood; 2, transection of medullary ray; 3, medullary ray, showing later stage of fungus attack; 4, 5, transection of wood cells; 6, starch grains from medullary ray cell; 7, starch grains from diseased wood; 8, transection from entirely rotted wood.



CROSS SECTION OF DISEASED TRUNK OF WHITE ASH KEPT IN A MOIST PLACE FOR SEVERAL WEEKS
(SHOWING GROWTH OF MYCELIUM FROM THE ROTTED PART)

HUNTTYER CO., BOSTON.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 33.

B. T. GALLOWAY, Chief of Bureau.

NORTH AMERICAN SPECIES OF LEPTOCHLOA.

BY

A. S. HITCHCOCK,

Assistant Agrostologist, in Charge of Cooperative Experiments,

GRASS AND FORAGE PLANT INVESTIGATIONS.

Issued February 10, 1903.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., October 18, 1902.

Sir: I have the honor to transmit herewith a technical paper entitled "North American Species of Leptochloa," and respectfully recommend that it be published as Bulletin No. 33 of the series of this Bureau.

This paper was prepared by Mr. A. S. Hitchcock, Assistant Agrostologist, in Charge of Cooperative Experiments, Grass and Forage Plant Investigations, and has been submitted by the Agrostologist with a view to publication.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

There is much confusion in the names applied to our North American grasses. This is partly due to the fact that much new material has been collected since the revision of some of the important genera. The practice, formerly more prevalent than at present, of erecting new species on the basis of a single specimen or of a very few specimens at most, has added to this confusion. The economic importance which the grasses have assumed in the last two decades has made this confusion all the more embarrassing. It therefore seems desirable that the bibliography, synonymy, and systematic relationships of American grasses be worked out as rapidly as possible. The present paper by Professor Hitchcock is an attempt to do this for the genus *Leptochloa*. It is based chiefly upon the material in the herbarium of the U. S. National Museum and that of the U. S. Department of Agriculture, but all the important public herbaria in this country were consulted during its preparation. The descriptions of the species are diagnostic rather than complete, but it is hoped that these will serve the purpose of students of systematic botany. Much time has been spent in working out the proper relationship of the species and it is hoped that the short descriptions, the text figures illustrating the spikelets of each species, the plates taken from herbarium specimens of several species, and the key to our United States species will take the place of more complete descriptions and render this paper valuable to students of this genus.

The species of *Leptochloa* are inhabitants of the warmer regions, only one or two of our species extending as far north as New York and Illinois. One of the species, *Leptochloa dubia*, called sprangle, is an important range grass in the Southwest, and recent experiments indicate that it will prove a desirable grass for cultivating in semiarid regions.

W. J. SPILLMAN,
Agrostologist.

OFFICE OF THE AGROSTOLOGIST,
Washington, D. C., October 14, 1902.

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[All five times natural size.]

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NORTH AMERICAN SPECIES OF LEPTOCHLOA.

INTRODUCTION.

In presenting the following review of the genus Leptochloa I have been able to bring together our knowledge of this group of grasses without describing any new species. In regard to the latter, botanists will probably be thankful. But, on the other hand, I have been constrained in several cases to unite species kept separate by others. All will not agree with me in the course I have taken in this respect. It is always difficult to decide where specific lines shall be drawn, but I have been governed by this rule: When two or more forms are connected by numerous intergrading specimens they are to be considered as the same species, although typical specimens of the extreme forms may be easily distinguished.

The notes are based mainly upon the Herbarium of the U. S. Department of Agriculture, but through the kindness of those in charge I have had the opportunity to examine the collections at the Missouri Botanical Garden, the Gray Herbarium, the New York Botanical Garden, and the Philadelphia Academy of Natural Science. I have also examined the specimens in the larger European herbaria, to the directors of which I wish to express my thanks for the privilege.

For the purpose of this paper it seemed not worth while to enumerate all the specimens examined, but a number of representative specimens from numbered sets have been indicated for easier reference.

KEY TO SPECIES OF THE UNITED STATES

1. Spikelets usually short-pediceled (sessile in *L. spicata*, but flowers several), arranged somewhat distantly along the branches of the panicle, not so conspicuously one-sided as in the following group; 4 to several flowered (2-flowered in some forms of *L. dubia*) 2
1. Spikelets nearly sessile in two or more rows on one side of the branches of the panicle, 2 to 4 flowered and usually closely imbricated (more distant in *L. mucronata*) 7
2. Panicle simple or often reduced to a single branch or spike ..... spicata.
2. Panicle compound 3
3. Spikelets 4 (2) to 6 flowered 4
3. Spikelets many flowered, elongated 6

4. Flowering glume broad, truncate and more or less emarginate; sometimes slightly awned from the protrusion of the mid-nerve ..... **dubia.**
4. Flowering glume rounded at apex and short-awned or mucronate 5
5. Panicle 2 to 3 inches long. Plant with numerous culms, a few inches to a foot high; leaves 3 or 4 inches long ..... **viscida.**
5. Panicle larger, culms 2 to 3 feet tall, leaves a foot or more long .. **floribunda.**
6. Flowering glume awned ..... **fascicularis.**
6. Flowering glume awnless or mucronate ..... **imbricata.**
7. Spikelets usually 2-flowered, sometimes 3 or even 4 flowered, 1 to 2 mm. long, branches of panicle very slender, upper empty glume as long as or longer than the first flowering glume, latter obtuse ..... **mucronata.**
7. Spikelets usually 3 to 4 flowered, rather closely imbricated, spikes shorter and close set on the axis, forming a narrow panicle; empty glumes shorter than the first flowering glume 8
8. Sheaths scabrous, glumes sharp-pointed ..... **scabra.**
8. Sheaths smooth; flowering glumes rounded or truncate at apex 9
9. Sheath ciliate on margin above; flowering glume more or less awned. **domingensis.**
9. Sheath not ciliate; flowering glume awnless ..... **nealleyi.**

HISTORY OF GENUS.

The genus Leptochloa was established by Palisot de Beauvois.[a] To his new genus he refers *Cynosurus capillaceus*, *Eleusine filiformis*, and *E. virgata*. The last of these species is figured[b] and in the description[c] of plates he uses the name *Leptochloa virgata*. It may be inferred that he intends to make the new combination for the other two species, as in the index, page 166, he indents under Leptochloa the three names, *capillacea*, *filiformis*, and *virgata*. It may be remarked that if one intends to be very accurate in regard to citations these three species of Leptochloa should be referred to page 166 (the index) rather than page 71 in the body of the work, where the genus is described. The same remark would apply to the most of Beauvois's species.

Beauvois also established the genera *Diplachne*,[d] to which he refers *Festuca fascicularis* Lam., and *Rabdochloa*,[e] to which he refers *Cynosurus monostachyos*, *virgatus*, *domingensis*, *cruciatus?*, *mucronatus?*.

Kuntze substitutes Rabdochloa for Leptochloa because Beauvois assigns five species to the former and only three to the latter.

Professor Scribner unites these under the genus *Leptochloa*.[f] Professor Gray also placed *Diplachne* under *Leptochloa* as a section.[g] Nuttall[h] proposed the genus *Oxydenia* to include *O. attenuata* (*Eleusine mucronata*).

I have accepted the genus as delimited by Scribner, U. S. D. A. Div. Agros. Bul. 20:110. Our species all are annuals except *L. dubia*.

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[a] Essai d'une nouvelle Agrostographie, 71. 1812.
[b] l. c., Atlas, pl. xv, fig. 1.
[c] l. c., Atlas, 10.
[d] l. c., 80.
[e] l. c., p. 84.
[f] Proc. Acad. Phil., **1891**: 303.
[g] Man., Ed. I, 588.
[h] Gen. **1**: 76, 1818.

NORTH AMERICAN SPECIES.

A.—LEPTOCHLOA *proper*. *Spikelets 2 to 4 flowered, arranged close together on one side of the branches of the panicle.*

LEPTOCHLOA MUCRONATA Kunth. Rev. Gram. 1: 91. 1835. Transfers *Eleusine mucronata* Michx. (Pl. I, fig. 1; text fig. 2.)

Eleusine mucronata Michx. Fl. 1: 65. 1803. "Hab. in cultis Illinoensibus."

Festuca filiformis Lam. Ill. 1: 191, n. 1044. 1791. "Ex Amer. Merid. Comm. D. Richard."

Eleusine filiformis Pers. Syn. 1: 87. 1805. "Hab. in Americ. meridion."

Eleusine sparsa Muhl. Descr. Gram. 135, 1817. "Habitat in Carolina et Georgia."

Oxydenia attenuata Nutt. Gen. 1: 76. 1818. "On the banks of the Mississippi near New Orleans." Mr. Nuttall says: "To this genus belongs the *Eleusine filiformis* of Persoon, growing in the tropical regions of America, nearly allied to the present species," and is often quoted as the author of *Oxydenia filiformis*, but he does not make this combination.

Leptochloa filiformis Beauv. Agros. 71 and 166, 1812. Transfers *Eleusine filiformis* Pers. Roemer and Schultes (2: 580. 1817), also transfer *Eleusine filiformis* Pers. Presl, Rel. Haenk. 1: 288, 1830, gives as the locality "Hab. in Mexico, ad Sorzogon Luzoniae." In the herbarium of the U. S. Department of Agriculture are several specimens from India. I am unable to distinguish these from the American plant. Hooker includes these under *L. filiformis* R. & S. (Flora Br. India, 22: 298. 1896.) I have examined the Asiatic material in European herbaria and feel satisfied that *L. mucronata* occurs in southern Asia. It can be distinguished from the allied *L. chinensis* by the papillose sheaths.

FIG. 1.—*L. attenuata*.

FIG. 2.—*L. mucronata*.

Eleusine elongata Willd. ex. Steud. Nom. ed. 2, 1: 549, 1840. Labelled "Habitat in America meridionalis Humboldt." Types of this and the next examined in herbarium Willdenow.

Eleusine stricta Willd. l. c. Labelled "Habitat in San Domingo."

Leptochloa attenuata Steud. Syn. 209. 1855. Transfers *Oxydenia attenuata* Nutt. This is kept separate by Mr. Nash in Britton's manual, but the characters do not seem to me to be sufficiently constant for separation. This form is represented by Bush, Nos. 590, 403, 792, 793, and Eggert, 219a, from Missouri, and Palmer, 392, 401, from Indian Territory.

Leptochloa pellucidula Steud. l. c. "Duchaissing legit in Panama."

Leptochloa pilosa Scribn. U. S. D. A., Div. Agros. Cir. 32: 9. 1901. "Type specimen collected in sandy soil, Dappan, Travis County, Tex., 294, J. E. Bodin, September, 1891." Professor Scribner states that "This species is closely related to *Leptochloa mucronata*, but it is at once distinguished by its rigid leaves and papillate-pilose sheaths." The leaves are somewhat more rigid than is usual in this species, but the papillate-pilose sheaths are found commonly in *L. mucronata*.

Stems tufted 6 to 10 dm. high, erect or occasionally more or less decumbent at base and rooting at the nodes. Leaves numerous, flat and rather soft, varying from 1 to 3 or more dm. in length and as much as ½ cm. wide. Sheaths more or less pilose from a papillate base. Panicle often 3 dm. or more in length, consisting of numerous slender spikes, arranged along a central axis;

spikes usually 8 to 15 cm. long. Spikelets 3 to 4 flowered, 1 to 2 mm. long, rather distant on the axis, that is, scarcely overlapping. Empty glumes about equal, lanceolate, acute or acuminate, nearly as long as the spikelet, or sometimes longer, lower slightly narrower. Flowering glumes thin, awnless, smooth or somewhat pilose on the nerves.

The form separated as *L. attenuata* has large panicles, with acuminate empty glumes and flowering glumes pilose on nerves.

DISTRIBUTION.—*Virginia to Florida and west to California:* Hall, 777, 778; Wright; 765; Bush, 468, 590; Curtiss, 5998; Coulter, 785; Lindheimer, 212. *Mexico:* Palmer, 248, 22, 694, 749, 1364, 117, 50 (in part); Rose, 1542; Schott, 739, 590. *Yucatan:* Gaumer, 853. *Cuba:* Wright, 740 (in part), 741 (in part). *Porto Rico:* Sintenis, 3550.

Var. **PULCHELLA** Scribn. Bull. Torr. Bot. Club, **9**: 147. 1882. "Santa Cruz Valley, near Tucson."

DISTRIBUTION.—*Texas to Arizona:* Heller, 1884; Hall, 777, 778; Coues & Palmer, 511; Jones, 4176. *Mexico:* Palmer, 50 (in part), 50½, 694, 8; Wright, 1316. Differs from the type in the short branches of the panicle, 2–3 cm. long, and the short narrow leaves.

LEPTOCHLOA VIRGATA Beauv. Agrost., 166; Atlas, p. 10. 1812. Refers *Eleusine virgata* to his new genus *Leptochloa* (l. c. p. 71). (Fig. 3.)

FIG. 3.—*L. virgata*, from St. Croix.

Cynosurus virgatus L. Syst. Nat., Ed. X: 1759. No locality is given, but he refers to Sloan jam., t. 70., f. 2, which is probably this species. In Spec. Pl., Ed. 2, the locality is "Habitat in Jamaica." See Munro, "The Grasses of Linnæus's Herbarium," Proc. Linn. Soc. Bot. **6**: 33–35. 1862. Linnæus mentions that the lower flowers are subaristate.

Festuca virgata Lam. Ill. **1**: 189. 1791. "Ex ins. Domingi." States that the spikelets are aristate and "floscul. ultimis submuticis."

Eleusine virgata Pers. Syn. **1**: 87. 1805. Description taken from Lamarck, l. c.

Oxydenia virgata Nutt. Gen. **1**: 76. 1818. This is the citation often given, but is an error, as Nuttall merely says, "To this genus belongs *Eleusine filiformis* of Persoon . . . and we may probably add the *Eleusine virgata* of Jamaica."

Chloris polystachya Lag. Nov. Gen. **4**. 1816. The short description scarcely suffices to determine this plant. "Spicis pluribus, patentibus: calycibus flosculisque glabris, muticis: culmo compresso. H. in N. H. unde semina missit D. Sesse."

Chloris poæformis H. B. K. **1**: 169. 1815. "Crescit in calidissimis humidis fluminis Magdalene prope Mompox: item prope Guayaquil et San Bowndon Quitensium." As synonyms are given *Cynosurus virgatus* L., *Eleusine virgata* Willd., and *Leptochloa virgata* Beauv., but a new specific name is applied because there is already a *Chloris virgata* Sw. In the description it is stated that the awn is very short.

Leptochloa procera Nees in Syll. Ratisb. **1**: 2. 1828. Type examined at Berlin.

Leptochloa digitaria Willd., ex Steud. Nom. Ed. 2. **1**: 549. 1840. Types of this and the next examined in herbarium Willdenow. Both specimens labelled "Habitat in America Meridionalis, Humboldt."

Leptochloa unioloides Willd., l. c.

Leptochloa mutica Steud. Syn. **1**: 208. 1854. "Surinam Am. Austr." Type examined.

DISTRIBUTION: *Roatan Island:* Gaumer. *Mexico:* Liebmann 251, 252; Nelson 2768, 2483. *Cuba:* Rugel 193; Wright 3436, 740 (in part), 741 (in part); Combs 256. *Porto Rico:* Heller 4535; Sintenis 844. *Martinique:* Bourgeau 2375; Hahn 163. *St. Vincent:* Smith 577. *St. Croix:* Ricksecker 258. *St. Thomas:* Eggers 68. *Galapagos:* Anderson 44. *Brazil:* Riedel, Traill 1274. *Paraguay:* Morong 970.

LEPTOCHLOA DOMINGENSIS Trin. Fund. Agrost., 133. 1820. Transfers *Cynosurus domingensis* Jacq. (Pl. H. figs. 1, 2; text figs. 4, 5, 6.)

Cynosurus domingensis Jacq. Misc. **2**: 363, 1781. "Facie infra medium pilosa dorsa glabra."

Bromus capillaris Moench. Meth. 194, 1794. "Sub nomine Poae capillaris semina accepi," no locality given. Kunth refers this to *L. domingensis* (Enum. 1: 269) and the description applies, especially, "Folia lata infra glabra, supra deorsum scabra, basin versus pilosa," but Moench also says, "vaginæ glabræ." However, the pubescence is confined to the margin of the sheath.

Eleusine domingensis Pers. **1**: 87. 1805. "Hab. in Jamaica, St. Domingo."

Rabdochloa domingensis Beauv. Agrost. 176. 1812. Transfers *Cynosurus domingensis*, p. 84. He also refers *Poa domingensis* Pers. Syn. **1**: 88 to his genus *Rabdochloa*, and in this is followed by Kunth (l. c.).

FIG. 4.—*L. domingensis*, from Hidalgo, Tex.

FIG. 5.—*L. domingensis*, from Florida.

FIG. 6.—*L. domingensis*, from Central America.

Leptostachys domingensis Meyer. Esseq. 74. 1818. Transfers *Eleusine domingensis* Pers.

Leptochloa gracilis Nees. Syll. Ratisb., **1**: 4. 1824. Transfers *Chloris gracilis* H. B. K. See note under *L. dubia*. Nees in Agrost. Bras., 433. 1829, gives "Habitat in Brasiliis . . . (Sellow. Vidi in Herb. Reg. Berol.)"

Chloris gracilis H. B. K. Nov. Gen. **1**: 168. 1815. "Crescit in calidis Provinciæ Jaen de Biacamoros prope Tomependa, alt., 207 hex."

Leptostachys gracilis Meyer. Fl. Esseq., 74. 1818. Transfers *Chloris gracilis* to his new genus *Leptostachys*.

Our plants have the rigid, glaucous appearance of *L. virgata*, with involute leaves, but resemble *L. domingensis* in having the margin of the sheaths and the upper surface of the lower part of the blades ciliate or pilose. The awns are almost the length of the flowering glume. Grisebach distinguishes these by the length of the spikes and of the awns (Fl. Br. W. I.), thus, *L. virgata* with spikes 3–6 in. long and awns short or none; var. *gracilis*, awns about as long as glume, spikes 1½–2 in. long; var. *domingensis*, spikes 3–5 in. long and awns longer. The length of the awn can not be depended upon to distinguish these forms.

Stems ½ to 1 m. high, smooth and somewhat shining or glaucous, leaves long and narrowed to a slender point, involute; the tropical specimens have softer, flat leaves. Our specimens are probably introduced as the plant is not common within our borders. The drier climate would account for the involute leaves. The upper surface of blade near base is sparsely pilose with long weak hairs, the margin of the sheath is more densely ciliate. Panicles 1 to 2 dm. long

with numerous ascending branches 4 to 8 cm. The tropical specimens often have more ample panicles. Spikelets crowded, about 2 mm. long, 3 to 5-flowered. Empty glumes acute, lower narrow and shorter, about 1½ mm.; lower flowering glumes bear awns about their own length, upper with shorter awns or awnless.

DISTRIBUTION: *Florida along the coast south of Tampa*, Simpson. *Texas, Corpus Christi, and Hidalgo,*[a] Nealley. *South America and West Indies.*

LEPTOCHLOA NEALLEYI Vasey. Bull. Torr. Bot. Club, **12**: 7. 1885. "Collected in Texas by Mr. G. C. Nealley, for whom it is named."

Leptochloa stricta Fourn. Pl. Mex. **2**: 147. 1886. I have examined the type in Paris. "Vera Cruz (Gouin, n. 73)."

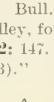

FIG. 7.—*L. nealleyi.*

Stems ½ to 1½ m. high, smooth. Leaves elongated or on the smaller plants only 5 to 10 cm. long, 3 to 5 mm. wide, involute, somewhat scabrous; sheaths smooth or very slightly scabrous. Panicles narrow, 2 to 4 dm. long, branches numerous, crowded, appressed, 2 to 6 cm. long. Spikelets crowded, about 2 to 3 mm. long, 3 to 4-flowered. First empty glume about one-half the length of the second and narrower; flowering glumes obtuse.

DISTRIBUTION: *Texas:* Nealley 2501: Bush 1363; Buckley, Drummond 291; Tracy 7368. This has the aspect of *L. scabra*, but the glumes are rounded at the apex, while in the latter they are acuminate or slightly awned. (Pl. III, fig. 2; text fig. 7.)

LEPTOCHLOA SCABRA Nees. Agrost. Bras. 435. 1829. "Habitat in ripa inundata fluminum Amazonum, Tagipuru et Tocantins, provinciæ Paraensis (Mart.)." Nees remarks that this differs from *L. virgata* in having the leaves and sheaths very scabrous and the small, whitish, slender spikelets entirely unawned. (Pl. III, fig. 1; text fig. 8.)

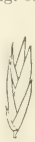

FIG. 8.—*L. scabra.*

L. langloisii Vasey. Bull. Torr. Bot. Club, **12**: 7. 1885. "This large and showy species was found in Louisiana by Rev. A. B. Langlois, for whom it is named."

Resembles *L. nealleyi* in habit. Differs in having distinctly scabrous sheaths; the branches of the panicle longer and more or less curved; the spikelets 3 mm. or more long, the glumes acute or acuminate. Our plants are probably introduced from further south.

DISTRIBUTION: *Louisiana:* In ditches and fields, Station Michaud, 13 miles from New Orleans, Langlois. *Brazil:* Rusby 235. *British Guiana:* Jenman 4441. *Costa Rica:* Tonduz 2604; Spruce 424.

[a] The specimen from Hidalgo (fig. 4) differs from the others in having the flowering glumes awnless. It is in an unsatisfactory condition, but may be *L. virgata*, Beauv.

B.—Intermediate between *Leptochloa* and *Diplachne*

LEPTOCHLOA VISCIDA Beal. Grasses N. A. **2**: 434. 1896. Transfers *Diplachne viscida* Scribn. (Pl. I, fig. 2; text fig. 9.)

Diplachne viscida Scribn. Bull. Torr. Bot. Club, **10**: 30. 1883. "Santa Cruz Valley, near Tucson, Arizona." Collected by Pringle.

Growing in tufts in moist places, 1 to 3 dm. high. Leaves a few cm. long, 2 to 3 mm. wide. Panicle short, 1 to 4 cm. long, more or less enclosed in the sheaths. Spikelets 3 to 4 mm. long, 5 to 7-flowered. First glume about one-half the second, ⅔ mm. long. Flowering glumes short awned, somewhat viscid on the back.

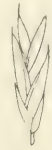

FIG. 9.—*L. viscida.*

DISTRIBUTION: *Arizona:* Pringle; Mearns 793, 833; Griffiths 1988. *New Mexico:* Wright 2041, 2044. *Mexico:* Pringle 814; Palmer 748, 748½, 692, 1789; Brandegee 5; Wright 1086.

LEPTOCHLOA DUBIA Nees in Syll. Ratisb. **1**: 4. 1824. In an article entitled "Novæ plantarum species in horto botanico Bonnensi cultæ," Nees ab Esenbeck, who signs the portion relating to *Leptochloa*, describes *L. procera*, and states that it differs from "*Leptochloa gracile*, Humb. et Kunth n. gen. et sp. I. p. 168 (sub chlori), vaginis glabris, valvulis corollinis nudis, nec ciliatis, apice integris, mucronatis, nec aristatis, flosculorum numero minore . . .

A Leptochloa (Chlori) dubia Humb. et Kunth l. c. p. 169; panicula æquali, nec subfastigiata, flosculorum numero minore, valvulis nudis, nec ciliatis . . ." He thus incidentally transfers these two species of *Chloris* to *Leptochloa*. (Fig. 10.)

FIG. 10.—*L. dubia.*

Chloris dubia H. B. K. Nov. Gen. **1**: 169. 1815. "Crescit in apricis subhumidis prope rupem porphyriticam el Penon, in convalle Mexicana, alt. 1168 hexap."

Leptostachys dubia Mey. Fl. Essequ. 74. 1818. Refers *Chloris dubia* doubtfully to *Leptostachys*.

Festuca obtusiflora Willd. in Spreng. Syst. **1**: 356. 1825. "Mexico." Type seen.

Uralepis brevispicata Buckley. Proc. Acad. Phil. **1862**: 93. 1863. "Northern Texas." I have examined Buckley's specimen in the herbarium of the Philadelphia Academy.

Diplachne dubia Scribn. Bull. Torr. Bot. Club. **10**: 30. 1883. Transferred to the genus *Diplachne*.

Leptochloa pringlei, Beal Grasses N. A. **2**: 436. 1896. "*D. pringlei* Vasey ined. Arizona, Pringle. 1884." In the Department herbarium is a specimen collected by Pringle in 1884 in Tucson (No. 13), which answers to the description given in Beal's Grasses, but seems to me to be a small form of *L. dubia*. This is figured in U. S. D. A. Div. Agrost. Bull. **7**: 224, fig. 218.

Diplachne dubia Pringleana O. K. Rev. Gen. Pl. **3**[2]: 348. 1898, transferred to *Leptochloa* by Scribner and Merrill, U. S. D. A. Div. Agrost. Bull. **24**: 27, 1901, is a robust variety from Chihuahua, Mexico (Pringle 422).

Stems 3 to 10 dm. high from a perennial root. Leaves long and narrow, tapering to a slender point as in *L. fascicularis* Gray, usually not over one-half cm. wide. Panicle, consisting of several or many more or less spreading spikes, 5 to 15 cm. long. Spikelets, 5 to 10 mm. long, 5 to 8 flowered, or in the smaller forms only 2-flowered. Empty glumes acute, upper 4 mm. long, lower a little shorter and narrower; flowering glumes broad and obtuse or emarginate at apex, the midrib sometimes extending into a short point. This species is readily distinguished by the broad, scarious emarginate apex of the flowering glumes. This is a valuable forage plant in the Southwest, where it is called "sprangle." Experiments indicate that it may prove valuable under cultivation in the arid regions of our Western States.

DISTRIBUTION: *Arizona:* Lemmon 368. *New Mexico:* Wooten 418. *Texas:* Jones 4210; Wright 767. *Florida:* Garber 33; Curtiss 3450; Simpson 302; Tracy 6453. *Mexico:* Palmer 270, 273, 530, 381, 482, 468; Bourgeau 533; Brandegee 6; Schaffner 671, 1079, 933; Pringle 422; Xantus 119; Botteri 690.

C.—DIPLACHNE. Spikelets several flowered, arranged more distantly on the branches of the panicle and not conspicuously one-sided.

LEPTOCHLOA FLORIBUNDA Doell in Mart. Fl. Bras. **2**[3]: 89. 1878. Type locality: "ad ripas fluminis Amazonum inter Manaos et Santarem (Spruce)." (Pl. VI, fig. 1; text fig. 11.)

Diplachne halei Nash. Bull. N. Y. Bot. Gard. **1**: 292. 1899. Type collected in Louisiana by Hale. Co-type in herbarium U. S. D. A.

FIG. 11.—*L. floribunda*.

Leptochloa halei Scribn. & Merr. U. S. D. A. Div. Agrost. Bull. **24**: 27. 1901. Transfers *Diplachne halei*. The relation of *L. halei* to *L. floribunda* is discussed in the article last cited. Going over the same evidence I believe that we are safe in making the present disposition.

Plant with the aspect of *L. fascicularis* Gray. Panicle oblong, rather compact, with numerous branches 4 to 6 cm. long. Spikelets 4 to 5 mm. long, 5 to 7 flowered. Empty glumes slightly unequal, upper about 2 mm., lower shorter. Flowering glumes with a very short point.

Probably introduced in the United States from farther south.

DISTRIBUTION: Texas to Brazil. *Key West:* Blodgett; *Mississippi:* Tracy 7451; *Louisiana:* Hale; *Texas:* Drummond 322; *Brazil:* Spruce 1112.

LEPTOCHLOA AQUATICA Scribn. & Merrill. U. S. D. A. Div. Agrost. Bull. 24: 26. 1901. "Type specimen collected in shallow water near Cuernavaca, State of Morelos, altitude 1700 m., C. G. Pringle, 6664 August 22, 1897." Resembles *L. floribunda*, but differs in having more unequal outer glumes, longer spikelets, with more distant flowers and obtuse flowering glumes. In *L. floribunda* the flowering glumes are distinctly short-awned. (Fig. 12.)

FIG. 12.—*L. aquatica.*

LEPTOCHLOA FASCICULARIS Gray. Man. Ed. 1, 588. 1848.

Festuca fascicularis Lam. Tabl. Enc. 1: 189. 1891. "Ex. Amer. merid. Comm. D. Richard." (Pl. IV, figs. 1, 2; Pl. V, fig. 1; text fig. 13.)

Bromus pœformis Spreng. Nach. Bot. Gart. Halle 15. 1801. Dr. Dammer, of the Royal Botanical Museum of Berlin, has kindly sent me a transcript of Sprengel's description. "*Bromus pœformis* mihi Pyrenæen," with reference to a footnote which says "*Poa digitata* Michaux. Sed est certissime *Bromus*, utut repugnet habitus: namque aristæ manifesto infra apicem glumæ oriuntur. Br. panicula erecta stricta composita, spicatis sex floris sub secundis, fol. longissimis involutis."

FIG. 13.—*L. fascicularis.*

Festuca polystachya Michx. Fl. 1: 66. 1803. "In arvis Illinoensibus." Type seen.

Diplachne fascicularis Beauv. Agrost. 80 and 160. Atlas, p. 11, pl. xvi, fig. 9. 1812. Made type of new genus without description of species.

Festuca procumbens Muhl. Gram. 160. 1817. A prostrate form with longer awns, but the characters are not constant, and it does not seem best to separate this as a species, as is done by Mr. Nash.

Diplachne procumbens Nash in Britton Man. 128. 1901. Transfers *Festuca procumbens* Muhl. There is a South American species by this name, *Diplachne procumbens* Arech. Gram. Urug. 354. 1894.

Leptochloa polystachya Kunth. Rev. Gram. **1**: 91. 1835 (or earlier?). Transfers Michaux's *Festuca polystachya*. Under the rule once a synonym always a synonym the Australian species should receive another name (*Leptochloa polystachya* Benth. Fl. Austr. **7**: 617. 1878). Bentham says (p. 618), "I have been able to retain Brown's specific name, as the American *Diplachne panicularis* [*fascicularis*] named *Leptochloa polystachya* by Kunth is generally retained under the former genus. Syn. *Cynodon polystachya* R. Br. Prod. 187. *C. virgatus* Nees in Steud. Syn. **1**: 213. *C. Neesii* Thw. Enum. Pl. Ceyl. 371."

Diplachne acuminata Nash in Britton Man. 128. 1901. Represented from Nebraska, Rydberg 1713; Arkansas, Coville 87; Colorado, Clements 263.

Uralepsis composita Buckley. Proc. Acad. Phil. **1862**: 94. 1863. "New Mexico. Dr. Woodhouse." I have examined this specimen in the herbarium of the the Academy.

Diplachne tracyi Vasey. Bull. Torr. Bot. Club. **15**: 40. 1888. "In clumps growing in ditches at Reno, Nevada." Tracy No. 216. Dr. Vasey remarks that this is "Near *D. fascicularis*." In the type specimen which is in the herbarium of the Department of Agriculture the lateral nerves are more conspicuously excurrent than is usual in *D. fascicularis*, but there seem to be no constant characters by which this form can be separated. It is a large form, with more exserted panicles, found from Nevada to Mexico, Pringle 813; Palmer 691.

Leptochloa tracyi Beal. Grasses N. A. **2**: 436. 1896. Transfers *Diplachne tracyi*.

Festuca multiflora Walt. Fl. Car. 81. 1788.

"Repens, paniculis erectis ovatis, spiculis 8 ad 40-floris acutis, floris angustis, acutis, fauce subplumosis." This may refer to *L. fascicularis*, but the description is scarcely sufficient. This plant is not represented in Walter's herbarium, which is at the British Museum.

Stems tufted, smooth, 3 to 12 dm. high, erect or procumbent. Leaves narrow, usually involute, 1 to 3 dm. long, 3 to 5 mm. wide; sheaths smooth or slightly scabrous. Panicles from a few cm. to 2 dm. long, more or less included in the upper sheath; branches of panicle few or several and of variable length, in the larger forms as much as 1 dm., appressed or ascending, or at maturity spreading. Spikelets usually somewhat overlapping, 7 to 12 mm. long, 6 to 12 flowered. Empty glumes narrow, acute, lower 2 to 3 mm. long, about one-half the upper; flowering glumes 4 to 5 mm. long, with an awn of variable length, sometimes, especially in the procumbent form, as long as the glume; lateral nerves pubescent below.

DISTRIBUTION: Maryland to Florida and west to South Dakota and New Mexico. *Texas:* Jones 4203; Drummond 387. *Kansas:* Hitchcock 920. *Florida:* Nash 2306. *St. Croix:* Ricksecker 306. *Cuba:* Wright 3822, 3812. *Mexico:* Pringle 813; Palmer 254, 691; Schaffner 683 (*D. procumbens*).

LEPTOCHLOA IMBRICATA Thurb. Bot. Calif. **2**: 293. 1880. "Larkins Station, San Diego County (Palmer No. 404); Fort Yuma (Major Thomas); and through the Gila Valley to the Rio Grande." (Pl. V, fig. 2; text fig. 14.)

Diplachne imbricata Scribn. in Vasey Ill. N. A. Grasses 1^2: No. 42. 1891. Transfers *Leptochloa imbricata* and gives a plate.

Diplachne verticillata Nees & Mey. Nov. Act. Nat. Cur. 19. Suppl. **1**: 158. 1843. (Not *Leptochloa verticillata* Kunth, 1835.) "Ad Copiapo in republica Chilensi, Martio 1831, et ad Aricam Peruviæ." The authors remark that this species differs from *Diplachne virens* of Brazil (presumably *Tridens virens* Nees) and *D. fascicularis* in having the glumes not awned from the apex but very shortly mucronate and from the first in its larger spikelets. I have examined *T. virens* Nees and think it is not identical with *L. imbricata* Thurb.

Leptochloa virletii Fourn. Pl. Mex. 2: 147. 1886. San Luis de Potosi" (Virl., n. 1404). Type specimen examined at Paris.

Rabdochloa imbricata Kuntze. Rev. Gen. 3: 788. 1891. Transfers *Leptochloa imbricata* Thurb.

Resembles in habit *L. fascicularis* Gray. The panicle is more oblong in outline, being more compact and with shorter branches, and often dark colored and more exserted. Spikelets also resembling *L. fascicularis*, but the empty glumes are broader and more obtuse, and the flowering glumes are somewhat apiculate but not awned.

FIG. 14.—*L. imbricata*.

DISTRIBUTION: *Arizona:* Palmer 548, 51; Lemmon 360; Vasey 540. *California:* Wright 2118; Coulter 776. *Texas:* Tracy 7367. *Mexico:* Palmer 47, 134, 331, 216, 5; Mearns 2741. *Argentina:* Hieronymus 1088. *Paraguay:* Morong 981.

There is a *Leptochloa verticillata* from the East Indies (Kunth Gram. 1: 91. 1835. *Eleusine verticillata* Roxb., Hort. Beng. 8. 1814).

Diplachne tarapacarum Philippi from Chili appears to belong here, judging from the specimen in herbarium U. S. D. A. (Anal. Mus. Nac. Chili. Bot. 88. 1891.)

LEPTOCHLOA SPICATA Scribn. Proc. Acad. Sci. Phila., 1891. 304. 1891. Transfers *Diplachne spicata*. (Fig. 15.)

FIG. 15.—*L. spicata*.

Bromus spicatus Nees. Agrost. Bras., 471. 1829. "Habitat in campis, campo mimoso dictis, provinciæ Piauhianæ." Nees observes that in habit this forms a transition to *Brachypodium* or *Agropyron*, but differs in the few nerved glumes; nor does it fit in *Diplachne* any better, since the native species has the glumes not at all apiculate, and foreign species differ much otherwise.

Tricuspis (*Triplasis*) *simplex* Griseb. Mem. Acad. Sci. and Arts. N. Ser. **8**: 532, 1862. Plant. Wright. 2. "In rupibus aridis." Wright, 1551.

Diplachne simplex Doell in Mart. Fl. Bras., 2^3: 97. 1878. "Habitat in prov. Piauhy (Gardner n. 2367)."

Diplachne spicata Doell l. c., 159. 1878. This is a correction. "Pag. 97. Deleatur *Diplachne simplex;* legatur *Diplachne spicata*, ut conservetur nomen specificum."

Triodia schaffneri Wats. Proc. Am. Acad., **18**: 181. 1883. "In the Escabrillos Mountains, San Luis Potosi (1077 Schaffner) closely resembling in habit the Cuban *Tricuspis simplex* of Grisebach and *Diplachne spicata* Doell of Brazil. It is clearly a *Triodia* as the genus is defined by Mr. Bentham."

Diplachne reverchoni Vasey. Bull. Torr. Bot. Club. **13**: 118. 1886. "Collected on granitic rocks, Llano Co., Texas, by Mr. J. Reverchon."

Triplasis setacea Griseb. in Goett. Abhandl., **24**: 304. 1879. Plantæ Lorentzianæ). "Pr. la Merced, S.: ad fl. Juramento." In his remarks upon this species Grisebach says: "Species *T. simplici* Gr. (Pl. Wright. Cub., II, p. 532) proxima."

Stems tufted, slender, 1 to 3 dm. high. Leaves usually about one-half the height of the flowering culm, numerous, narrow, slender, and involute. Inflorescence reduced to a single spike, 5 to 10 cm. long. Spikelets 4 to 7 mm. long, several flowered. Empty glumes acute, flowering glume short awned.

Distribution: *Texas:* Reverchon, 1613; Nealley, 78. *Mexico:* Pringle, 3267. *Argentina:* Hieronymus, 337. *Brazil:* Gardner, 2367.

Diplachne loliiformis F. von M. of Australia closely resembles this.

Besides those species mentioned above are three described by Fournier, which I have not seen. Copies of the original descriptions of these are here appended.

LEPTOCHLOA LIEBMANNI Fourn. Pl. Mex., **2**: 147, 1886.

Culmo elato 2–3 pedali, valde ramoso, stramineo, glabro; foliis infra longe vaginantibus mollibus lanceolatis, 4–5‴ latis, ligula fimbriata; panicula longa stricta, radiis appressis, secundifloris; spiculis 4-floris, glumis inæqualibus, inferiore aucta dimidio breviore, superiore obtusa obscure trilobata, lobo medio mucronato; palea exteriore acuta carinata.

Antigua, februario (Liebm., n. 248); absque loco (Liebm., n. 244).

DIPLACHNE PATENS Fourn. Pl. Mex., **2**: 148. 1886.

Culmo a basi ramoso, ramis circulariter ascendentibus glabro, striato, stramineo, nodis brunneis, ligula hyalina acuta sæpe laciniata, foliis longis linearibus angulo recto divergentibus, acutis; panicula invaginata, radiis alternis patulis flexuosis scabris, spiculis 7-floris; gluma inferiore dimidiam superiorem non æquante, exteriore violacea acuminata carinata scabra; rhachi inter flores flexuosa; palea inferiore carinata, nervo medio prominente acuminata, superiore duplo minore, bicarinata, obtusa, apice integra.

Vera Cruz (Gouin, n. 93).

LEPTOCHLOA PANICULATA Fourn. Bul. Soc. Bot. France (ser. 2), **27**: 296. 1880.

Culmo 3-pedali, cum nodis glabro; foliis latis brevibus, acuminatis, ligula brevi laciniata; inflorescentia pedali, axi paniculæ et radiorum scabro; radiis primariis primum patulis, dein divaricatis, in dimidia inferiore parte radiolos semipollicares emittentibus; spiculis 3–4 floris muticis, floribus remotis, glumis æqualibus, palea exteriore bidentata mutica.

Absque loco (n. 1079).

SPECIES EXCLUDED.

LEPTOCHLOA BRANDEGEI Vasey = **GOUINIA BRANDEGEI** Hitchc. (Fig. 16.)

FIG. 16.—*Gouinia brandegei*. Callus on right.

This was first described by Vasey (Proc. Calif. Acad., ser. 2, 2: 213. 1889). This agrees with the other species of *Gouinia* in habit and in general floral structure, such as the 1-nerved unequal empty glumes, the 3-nerved flowering glume, the rather long-pediceled rudimentary flower, and the hairy callus of the lower flower. It differs from the other species chiefly in the very short awn to the flowering glume.

DISTRIBUTION: *Lower California:* Brandegee 7, 9, 11, 38. *Carmen Island, Mexico:* Palmer, 362.

Leptochloa rigida Munro = *Eragrostis sessilispica* Buckley.

Leptochloa palmeri Vasey ined. = *Gouinia virgata* Scribn.

Leptochloa mexicana Scribn. = *Gouinia mexicana* Scribn.

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DESCRIPTION OF PLATES.

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III. Fig. 1.—*Leptochloa scabra* Nees. Louisiana, Langlois. This is the specimen upon which was based *Leptochloa Langloisii* Vasey. Fig. 2.—*Leptochloa nealleyi* Vasey. Texas, Nealley. Type specimen.

IV. Fig. 1.—*Leptochloa fascicularis.* The prostrate form that has been named *Diplachne procumbens* Nash. Denver, Colo., Letterman. Fig. 2.—*Leptochloa fascicularis.* The western form which has been named *Diplachne tracyi* Vasey. Reno, Nev., Tracy, 216. Type specimen of *D. tracyi* Vasey.

V. Fig. 1.—*Leptochloa fascicularis* Gray. Sheffield, Mo. Bush No. 804. The ordinary form. Fig. 2.—*Leptochloa imbricata* Thurb. Cultivated in Grass Garden, U. S. Department of Agriculture.

VI. *Leptochloa floribunda* Doell. The cotype of *Diplachne halei* Nash. Louisiana, Hale. A fragmentary specimen, but interesting because of its history.

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FIG. 1.—LEPTOCHLOA MUCRONATA.

FIG. 2.—LEPTOCHLOA VISCIDA.

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FIG. 1.—LEPTOCHLOA DOMINGENSIS, FROM FLORIDA.

FIG. 2.—LEPTOCHLOA DOMINGENSIS, FROM TEXAS.

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FIG. 1.—LEPTOCHLOA SCABRA.

FIG. 2.—LEPTOCHLOA NEALLEYI.

Bul. 33, Bureau of Plant Industry, U. S. Dept. [illegible]

FIG. 1.—LEPTOCHLOA FASCICULARIS (DIPLACHNE PROCUMBENS NASH).

FIG. 2.—LEPTOCHLOA FASCICULARIS (DIPLACHNE TRACYI VASEY).

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FIG. 1.—LEPTOCHLOA FASCICULARIS (ORDINARY FORM).

FIG. 2.—LEPTOCHLOA IMBRICATA

FIG. 1.—LEPTOCHLOA FLORIBUNDA.

MULBERRY TREES AND LEAF GATHERERS, LOMBARDY, ITALY.

Photographed August 26, 1902, by Dr. L. O. Howard.

U. S. DEPARTMENT OF AGRICULTURE.
BUREAU OF PLANT INDUSTRY—BULLETIN No. 34.
B. T. GALLOWAY, *Chief of Bureau.*

SILKWORM FOOD PLANTS:

CULTIVATION AND PROPAGATION.

BY

GEORGE W. OLIVER, EXPERT,
SEED AND PLANT INTRODUCTION AND DISTRIBUTION.

ISSUED JANUARY 15, 1903.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief.
Washington, D. C., October 27, 1902.

Sir: I have the honor to transmit herewith a paper entitled "Silkworm Food Plants: Cultivation and Propagation," by George W. Oliver, Expert, Seed and Plant Introduction and Distribution, and respectfully recommend its publication as a bulletin of this Bureau.

The paper has been prepared at the request of Dr. L. O. Howard, under whose direction the funds appropriated at the last session of Congress for an investigation into the subject of silk culture in this country are expended. Dr. Howard has made a number of suggestions in regard to the scope and character of the paper, and has furnished the illustration used as a frontispiece, selected from a large number of photographs taken by him during the past summer while investigating the silk-cultural industry in Italy and other countries.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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SILKWORM FOOD PLANTS, CULTIVATION AND PROPAGATION.

INTRODUCTION.

There is a small family of plants closely allied to each other, a few of which supply the silkworm with food. This family is called *Moraceæ*. There are three genera of trees in the group—*Morus*, the mulberry (Pls. I, II, III, IV, V, and VII); *Toxylon*, the Osage orange (Pl. VIII), and *Broussonetia*, the paper mulberry (Pl. VI). The last named, being unsuitable for silkworm food, will not again be referred to here.

The Osage orange provides palatable food for the silkworm, and if the worms were free to select the leaves for themselves the tree would be satisfactory; but the leaves are selected for them often with bad results, for the young and immature leaves have a tendency to sicken the worms. Ignorance of this fact renders the use of the Osage orange dangerous.

Of the mulberry there are many so-called species and a great many varieties, but there are only one or two species and a few varieties which are of importance in silkworm propagation. Chief among these for producing silkworm food is the white mulberry, *Morus alba* (Pl. I). This is thought by some to be a native of China. It has long been known that the white mulberry and its varieties are hardy over a large area of the United States.

The uninitiated should not be left to their own devices in growing mulberry trees, especially if the enterprise is to be an extensive one, for if failure results, silkworm propagation in the particular section of the country where the experiment is conducted will receive a serious setback.

It is not the purpose of this paper to discuss the question of the most suitable varieties of the white mulberry, as this could only be done from a European point of view. Bureau, in his monograph, describes 27 varieties of the white mulberry alone. In Italy, silkworm growers favor *Morus alba*, variety *moretti*, and forms raised from it. France and Spain have each its favorite kinds. Japan has

close upon 100 forms, one or two of which would probably answer all purposes, while most of the silkworms reared in China are said to be fed upon *Morus multicaulis*. This mulberry was largely planted in the United States many years ago. Few, if any, of the original trees remain, but specimens which are thought to be wild seedlings of these are very plentiful in the Southern States. These trees are thoroughly acclimated and free from disease. It is therefore probable that there is now in the United States an abundant supply of material for propagating purposes, at least.

It is intended to show in these pages how the mulberry may be propagated and grown so as to provide the maximum amount of leaves for the food supply of the worms. The white mulberry, under good cultivation, is a low-growing tree, seldom attaining a greater height than 25 or 30 feet. It will reach this height in a comparatively few years after planting. Although it will live to a good old age, its growth, like that of most other trees, is most rapid when young. As the trees attain their full height they become stocky and make a multitude of small growths, from which flowers and fruit are produced. The fruit, which is usually abundant, is not a favorite in this country, being generally considered too sweet and insipid. In shape it may be said to resemble more or less that of an elongated blackberry. In the vicinity of Washington the trees flower about the middle of May and ripen their fruit during June.

METHODS OF REPRODUCTION.

The usual methods of propagation in use for fruit trees are employed with varying degrees of success in the case of the mulberry. These methods consist of budding, grafting, layering, cuttings, and seeds.

Grafting and budding are by far the most expensive methods, and it is doubtful if the results justify their use, so far as raising mulberry trees is concerned. Part of the work connected with budding and grafting consists in raising stocks, which are seldom large enough for use until they are two years old. At this age, the buds or grafts are inserted, and then troubles previously undreamed of present themselves to the inexperienced cultivator. Were the mulberry tree as easily managed so far as budding or grafting is concerned as is the peach, the use of these methods would be feasible, but unfortunately the mulberry is far from being an easy subject in this respect, and a few failures are apt to produce disappointment and disgust. It will frequently happen that old trees must either be removed or desirable varieties worked on them; budding or grafting may be resorted to in such cases.

Layering consists in bending down a portion of a branch so that its stem after being notched may take root in the ground while still attached to the parent tree. It is a cumbersome method, however.

Although good-sized plants can be raised in a short time by its use, it is seldom employed when any other method will produce the same results.

Raising young trees from cuttings of the 1-year-old ripened wood is a method which requires but little skill. As with budding and grafting, this method is instrumental in perpetuating varieties, as every rooted cutting will eventually be a reproduction of the tree from which it was taken. This is not the case with plants raised from seeds, which always vary considerably from the parent. For this reason some mulberry growers in Europe object to the seed method. Some of the seedlings, even from a single parent tree, will vary greatly in the value of the leaves for feeding purposes. Some will be thin in texture and lacking in the necessary chemical constituents; some, very hairy; others thick, smooth, and in every way desirable. However, experienced mulberry growers can readily tell the value of a seedling tree for feeding purposes, and it is therefore possible to make a selection in this respect without much loss.

PROPAGATION BY CUTTINGS.

SUMMER CUTTINGS.

In any group of seedlings there will always be found individuals the leaves of which possess great adaptability for feeding purposes. These should certainly be propagated to perpetuate this desirable characteristic. Propagation should be started after the seedlings have made considerable growth in order to insure a good supply of wood. These plants should be increased by cuttings during the summer months. At this season it is advisable to retain some of the leaves on the cutting and give treatment which will prevent shriveling during the process of rooting. The cuttings should be made from wood as ripe as possible; the leaves, besides being well matured, should be healthy and free from noxious insects. During July the lower parts of the current season's shoots will be found in good condition for propagating.

Trim the cuttings similarly to those shown in Pl. IX. At least two leaves shortened to one-half their length should be allowed to remain on the cutting. When placed in the propagating bed, the slips should be inserted in the sand in a direction sloping from the operator. Good results will follow if a cool propagating house is used, with clean sand as the rooting medium. When a propagating house is not available, a wide frame provided with sash will answer the purpose. The frame should face north, and if in the shade of trees, so much the better. The sash should be kept closed, so that a humid atmosphere may be maintained until the cuttings take root. After they have made a considerable quantity of roots in the sand they should be transferred

to beds in the open. The beds should be 5 feet wide. Place the rooted cuttings about 6 inches apart each way and water copiously until established, when they must be freely exposed to air and sunshine.

WINTER CUTTINGS.

The cutting.—The principal supply of plants may be secured by propagating from cuttings, which should be made from dormant wood taken from the trees just after the leaves have fallen.

In no case should the cutting wood be less in diameter than a quarter of an inch. The cuttings (Pl. X) should be about 10 inches in length, making the upper cut about one-half inch above a bud. The position of the lower cut is immaterial. The cuttings should now be tied in bundles of fifty and either stored for the winter or be immediately put out where they are to root. Where the winters are not too severe, or in the Eastern States south of the thirty-ninth parallel, they should be put in the ground during autumn. North of this it will be found best to keep them under cover until the ground is in a condition to be worked in early spring. If they are kept even for a short time in a dry place, they will lose their sap and become shriveled. Therefore they should be buried in moderately moist sand or sand and ashes. Under such conditions a good callus will have formed around the lower cut surface before the time arrives when they are to be put in the open. If sphagnum moss be easily procurable, it can be used very successfully as a substitute for sand or ashes; but in this case the bundles of cuttings should be smaller and they should be placed with the buds pointing upward, the moss to be packed tightly around them, with the top part uncovered. This is an excellent method for inducing the formation of a good callus.

Preparations for planting cuttings.—Previous to putting the cuttings in the open the soil should be plowed deeply, then harrowed and rolled until well pulverized. A furrow is made with a spade to a sufficient depth, a little sand placed in the bottom, and the lower ends of the cuttings placed on top. Fill in the soil to half the depth of the furrow, firm well with the feet, then fill in the remainder of the soil, leaving only enough of the cutting exposed to view to keep the top bud from being covered. Where there is danger of hard freezing weather after fall planting, cover the surface with rough stable litter or dead leaves, this covering to be removed before the buds begin to swell during the latter part of March.

The rows of cuttings can be arranged in beds of any convenient width, leaving spaces between the beds; this arrangement will facilitate covering, watering, and hand-weeding. If plenty of good ground is available, enough space should be left between the rows to permit of horse cultivation. During the summer the plants should be gone over several times and all superfluous shoots removed, leaving only

one shoot to each plant. If large enough, the rooted cuttings should be removed to nursery rows the following fall. In no case should the plants be removed from the cutting beds to permanent locations.

If the plants make sufficient growth the first season, they should be severely cut back; otherwise the operation should be deferred until the following season. The length of stem to remain as the future trunk must be regulated according to whether a dwarf or tall specimen is wanted. It must be taken into consideration that the leaves are much more easily gathered from dwarf trees than from tall ones; in fact, they are more easily managed, not only so far as leaf gathering is concerned, but also in pruning and in keeping noxious insects and fungus diseases under control. The leaves on a tall tree are not all developed alike; those on the side fully exposed to the sun will naturally be in perfect condition, while on the opposite side they are softer and probably not so well adapted to the purpose for which they are intended. Medium-sized trees are therefore preferable for all purposes.

INDOOR SPRING CUTTINGS.

Another method of propagation from cuttings, and a very successful one, consists in selecting medium-sized shoots about the beginning of November. These, before being made into cuttings, are sorted into bundles of different lengths, tied, and heeled in ashes or sand, or in a mixture of both, and protected by a frame having a northern exposure. During the winter they are taken out and cut into lengths of about 5 inches. These are tied in bundles and buried in moist sand or moss. In early spring they are untied and put quite thickly in a propagating bed having a mild bottom heat, where they will root rapidly. When such a bed is lacking, wooden flats about 4 inches deep may be used for the reception of the cuttings; but they must have the protection of a frame covered with sash. If a little loamy soil is placed in the bottom of the flats the cuttings will remain in good condition for a considerable time after rooting and until a favorable opportunity arrives for planting them out in nursery rows. If those rooted indoors are given plenty of air after being rooted in the bed, they can be transferred to the open ground with safety during dull weather.

PROPAGATION BY SEEDS.

The most convenient and rapid method of propagation is undoubtedly from seeds, as they are quick to germinate and the seedlings make growth about as rapidly as plants raised from cuttings. Seeds sown shortly after being harvested will germinate in a few days. If kept over winter and sown in early spring, the seedlings will appear within fourteen days. When the seed is spring sown, the seedlings will, if the weather be propitious, attain a height of from 12 to 18 inches in

one year; but during dry seasons they will only grow from 6 to 12 inches. Seedlings from seeds sown immediately after the fruit ripens are always small at the end of the season, but they produce strong plants the season following.

Seed is usually produced in great abundance by nearly all of the species and their varieties. The mulberry, like the strawberry, blackberry, and raspberry, does not ripen all of its fruit at one time; consequently several gatherings are necessary before a crop is harvested from any one tree. The earliest fruits can be gathered immediately after they are ripe and the seed sown if desired. It should be remembered that seedlings thus raised have comparatively little time to make their growth; therefore, every day counts.

In gathering the fruit, it will be found easiest to shake the tree and pick the fruits from the ground. To remove the seeds from the surrounding pulp, put the fruit into a large bucket or tub and squeeze with the hands until it becomes a jelly-like mass. Add water and stir well until the contents are thinned sufficiently to allow the seeds to sink to the bottom. The remaining material can be poured off. The seeds should be exposed to the air until dry. If it is desired to sprout them the same summer, they should be sown in beds in the open, the soil of which should previously be well worked by deep plowing and gone over several times with a harrow and a roller. When the soil is sufficiently pulverized the ground should be marked off into beds 5 feet wide and of any convenient length, leaving a space of 2 feet between the beds. To prevent washing of the soil and also to minimize the evil effects of drying winds, drive some stout stakes into the ground along the sides and ends of the beds, and to these nail eight or twelve-inch boards. The surface of the bed should be leveled and all stones and roots of plants removed with a hand rake.

Sow the seeds broadcast, taking care not to sow them too thick, as there is a danger of the seedlings crowding each other. Crowding produces weak plants, because even the best soil is capable of supporting only a certain number of plants to the square foot. Press the seeds into the soil with the back part of a spade and cover lightly with soil screened through a quarter-inch sieve.

In order to have the best results, the seed beds should not be exposed to the sun until a considerable time has elapsed after germination. This condition may be arranged as follows: Procure some pieces of 2 by 3-inch scantling; place two of the pieces parallel to each other 5½ feet apart. Nail laths from one to the other, using the 2-inch surface in which to drive the nails. Leave 1-inch spaces between the laths. The slats are put lengthwise over the beds, and can be used with or without the side boards. Over the slats spread archangel mats, or canvas, until germination takes place; these coverings should be frequently dampened. After the seedlings show above the ground, the

cloth coverings are to be kept on during the hottest part of the day only, and when the first true leaf appears they may be removed altogether and the shade necessary thereafter supplied by the lath slats. Water must be supplied if the soil needs it. With spring-sown seed, the coverings over the lath slats may be dispensed with, but the surface of the bed should not be allowed to become dry until the seedlings are large enough to take care of themselves.

GRAFTING AND BUDDING.

In Italy and other silk-raising countries it is claimed that the leaves of trees raised from cuttings and seeds are superior for silk production, but that the quantity of leaves produced by trees so propagated is only about one-half the bulk of those from grafted or budded trees. Therefore, to produce a large quantity, grafting and budding methods of propagation are practiced to a great extent. Before the beginner undertakes these expensive methods of propagation in the United States, however, he should consider that land rentals are high in Europe and that land is cheap in the United States; therefore the American can afford to grow more trees by the methods which are instrumental in giving the best grades of silk. This is an important point to consider, and the writer is inclined to the belief that in the propagation of plants giving the highest grades of silk there will be little danger of a scarcity of material, as the mulberry thrives as well, if not better, in most parts of the United States as anywhere in Europe.

For those who decide to try propagating by grafting and budding two of the most successful methods of performing the operation are here described.

ROOT GRAFTING.

This is performed in February and March. The stocks, which are two-year-old seedlings of the Russian mulberry (*Morus alba*, variety *tatarica*), should show a diameter of at least three-eighths of an inch to give a satisfactory union. The stocks should be lifted in the fall and "heeled in" out of the reach of frost. The scions should be cut while in a dormant state and buried in damp sand in a protected place.

In the latter part of February the work of root grafting (Pl. XI) may be started. The preparatory work consists in securing a quantity of strong tidy cotton, and of grafting wax made of beeswax two parts, of resin two parts, and of mutton tallow one part. Put the ingredients in a small tin bucket, place on a hot stove, and when melted drop in one or more balls of the cotton, allowing them to remain in the melted wax for five minutes; remove with a pointed stick. When cool they are ready for use. Procure a deep box in which place the stocks, keeping them covered with a dampened sack; another box

should be provided for the scions similarly protected, and a third one for the grafted roots. These precautions are necessary, as a little exposure to dry air is always detrimental.

In beginning work with the stocks sever the top from the root at the collar; this can be done best with a pair of pruning shears. Take a scion at least 8 inches long and attach by the tongue method, as shown in Pl. XI. Select stocks and scions of as nearly the same diameter as possible; make a slanting cut at the bottom of the scion and a similar cut at the top of the stock. In the case of the scion, make an upward incision at a point about one-third of the length of the cut surface from the base; this will form a tongue. Next make a corresponding incision downward near the top of the slanting cut on the stock. The idea is to have the tongue of the scion take the place which the knife blade occupies when making the incision in the stock. When the two parts are neatly fitted so that the bark of stock and of scion come neatly together at one side, or at both if possible, bind firmly with the waxed cotton. This material should be used in preference to raffia, because when the grafted stock is buried in the ground, raffia would be certain to rot before the union took place, while cotton will remain in good condition for a long time.

After the fitting and tying have been done, the grafted stocks should be tied in bundles of twenty-five, the first tie to be made rather firmly near the upper part of the scions; secure them again near the base of the scions, but not as firmly as before. Care must be taken so as not to displace the fitted parts. The bundles should now be buried in sand in a frame or other protected place until planting time arrives. The grafted stocks should be planted out just as soon as the condition of the soil will permit. Plant them deep enough so that only the top bud is exposed to the light.

The subsequent treatment is in all respects similar to that given for cuttings. Mark the kinds, with the dates of grafting and planting, on large labels which will not be easily displaced.

SCION OR SPRIG BUDDING.

Scion or sprig budding, as shown in Pl. XII, is perhaps the most successful and easiest to accomplish of all methods. It is practiced on stocks which have not been transplanted for at least one year previous to the time when it is desired to bud. The stocks should be larger than those used for root grafting. The most desirable time for the operation is in spring, when the bark lifts easily; this will necessarily be after the stocks come into leaf. The scions must be selected from shoots of the previous season's growth, short and stocky, with two buds present (Pl. XII, A and B). They should be cut from the parent plants in the fall and kept dormant until the opportune moment arrives when the stock plants are in a receptive condition.

In preparing the stock for the scion the preliminary work is similar to that in shield budding the peach, cherry, or rose. At a point a little above the collar of the stock a transverse cut is made through the bark for a distance of half an inch or more around the stem (Pl. XII, C.) This is followed by a longitudinal cut, beginning in the middle of the first cut and extending downward for about an inch. Prize up the bark at each side of the long cut (Pl. XII, C) and it is ready for the scion, which is prepared for insertion by making an oblique cut through the base, so as to leave a cut surface about an inch long (Pl. XII, A and B). The scion is then fitted in place so that its cut surface is neatly placed against the wood of the stock (Pl. XII, D) laid bare by the raising of the bark. The next operation is shown in Pl. XII, E, and consists in tying the parts together so that they will be held firmly while the union is taking place. In order to exclude air and moisture, grafting wax or clay should be applied, as shown in Pl. XII, F.

Within two weeks from the time of budding, the union will be effected, if everything has gone well. The ligature should not be removed, however, until there is danger of its cutting into the bark. The most essential part of the subsequent treatment consists in heading back the stock, so that the future head of the tree will be formed by the growth of the scion, and to do this successfully good judgment must be exercised. Cut off only a part at first, leaving some foliage on the stock until the buds on the scion begin to push, when that part of the stock above the union should be removed with a sharp knife. Cover the wound thus made with grafting wax.

SHIELD BUDDING.

The shield system of budding may be used, but only in the spring, as the mulberry does not take kindly to shield buds inserted during the season suitable for most of our fruit trees.

Shield budding consists in selecting a stock, either a branch or stem, from which the bark slips readily. In raising the bark of the stock for the reception of the bud, the work is similar to that described for scion or sprig budding. The bud is usually selected from dormant wood kept over winter in ashes or sand; but for this there exists no necessity, because there is always present an abundance of dormant buds on a growing plant, and these answer the purpose much better than buds from dormant wood. To remove them, with a sharp knife make an incision in the stem about five-eighths of an inch below the bud; bring the blade up under the bud, severing a section of bark three-eighths of an inch in width, with the bud in the center; bring the blade out a little above the bud. If this operation is neatly performed the bud will require no further trimming before being inserted under the bark of the stock. The bark of the stock is then firmly bound over that of the bud and the parts kept in position with raffia. No

waxing is necessary. The union should take place within fifteen days, after which the ligature should be loosened or removed as proves necessary.

RAISING STOCKS FOR GRAFTING AND BUDDING.

In grafting and budding from any particular variety which it is desired to perpetuate, the Russian mulberry, *Morus alba*, variety *tatarica*, is the one used as stocks. It is of a robust-growing nature and has been found well adapted to the soils and climates of all the agricultural belts of the United States. It is this variety that is so much used in the West and Northwest for hedges, as it is the hardiest of all the mulberries.

Stocks are best raised from seeds, and a supply for this purpose should be obtained from a reliable source, to avoid unnecessary delay and disappointment. The sowing and the subsequent management of the seedlings are the same with stocks as with seedlings for general planting, except that when planted in nursery rows they should be placed about a foot apart, so as to give an abundance of space for the operator to work.

SOIL.

So far as has been ascertained, the mulberry is not particular as to the character of the soil. It seemingly grows equally well in a great variety of well-drained soils. Even in sandy and gravelly situations it holds its own. In shallow soils over hardpan the mulberry thrives after most of our fruit and ornamental trees have given up the struggle. Under the same conditions the Persian mulberry has been found to fruit abundantly.

Notwithstanding its behavior under what would be supposed adverse conditions, there are few plants which respond more vigorously to applications of manure. In Japan it has recently been shown that by liming alone the percentage of fiber in the leaves decreased very perceptibly. Again, by liming and also manuring with sodium nitrate and calcium sulphate a still further reduction in the fiber was apparent. The trees operated on were 1½ meters (5 feet) high. Each tree was treated with 500 grams (1.1 lbs.) of lime, 400 grams (.9 lb.) of sodium nitrate, and 200 grams (.44 lb.) of calcium sulphate. How the caterpillars fared as a result of this change in the composition of the leaves is not stated.

PLANTING.

This all-important operation may be performed either in the fall or spring. After the leaves have fallen or are matured, no delay should occur in transplanting to permanent positions. When this period is selected, it gives good opportunities for the formation of new roots.

In spring the trees may be transplanted any time after the ground is in a workable condition and up to the period when the buds are about to burst into growth. Spaces intended to be planted should be deeply worked beforehand by plowing and harrowing, and after planting the weeds should be kept down.

The distance between the trees should not be less than 10 feet in the rows, and the rows should be the same distance apart. If the field devoted to the trees is more than 2 or 3 acres in extent, wider spaces should be left at intervals for wagons, etc. It is certain that trees planted 10 feet apart will eventually occupy all the space; but when there is danger of their becoming too much crowded, enough of the plants may be rooted out and burned to allow the remainder abundant space to develop. If this is done, those which are to remain permanently should be trained accordingly. The above arrangement is the best for trees nearly all the branches of which can be reached from the ground, not only for pruning, but also for leaf gathering.

In planting trees similar precautions should be taken to those in the case of ordinary forest trees; that is, not to allow the roots to become in the least dry from the time they are lifted from the nursery rows until planted in the field. As soon as they are lifted the roots should be dipped in a mixture of soil and water and kept covered until planted, so that they will not become dry. If the ground is naturally hard and the soil is poor, dig large holes, even for very young trees, as they grow rapidly and should be encouraged to make good, stout growths from the beginning. Put some good soil in the hole, spread out the roots on this, and cover with several inches of fine soil before firming with the feet. Allow the roots to be about the same depth in the hole as they were in the nursery rows. Prune back the growth of young trees one-half in the fall, and if necessary cut back to strong buds in early spring.

PRUNING.

The pruning of the trees presents no special difficulties so long as it is done early enough in the season to avoid late growth, which, if caught by cold weather before ripening, will perish during the winter. The principal pruning should be done in winter and should consist of shortening back strong growths so as to form a low, spreading tree. Keep the central part of the tree as free of growth as possible, to admit light and air.

After the first cutting back, select three or more of the strong shoots to form the principal branches. If they are strong and show a disposition to grow upright, they may be kept apart by using three sticks tied in the shape of a triangle; place these in the center of the tree and tie the branches to them until they grow in the desired

direction. By careful attention to cutting out the undesirable growths the tree can be made to assume any desired shape.

In gathering the leaves always allow enough to remain on the tree to insure its perfect health. If some of the trees show signs of failing vigor as a result of excessive leaf gathering, it is advisable to allow them to grow for a season without picking, and by early pruning out of unnecessary growth permit those growths which are desirable to become ripened.

PLATES.

DESCRIPTION OF PLATES.

FRONTISPIECE.—Old mulberry trees, showing Italian method of pruning, with a group of embryo silk culturists (leaf gatherers) in the foreground, Lombardy, Italy. By this method of pruning, tall trunks from 8 to 10 feet from the ground are produced, necessitating the use of ladders for leaf gathering. From a photograph taken August 26, 1902, by Dr. L. O. Howard.

PLATE I. Branch of the white mulberry, *Morus alba*, with large undivided leaves, of thick texture and smooth surface. The leaves of this variety are preeminently adapted for silkworm food. From photograph of a tree in the grounds of the U. S. Department of Agriculture.

II. Branch of seedling white mulberry, *Morus alba*, with divided leaves. Seedlings from the same parent will sometimes have leaves of the divided form, others assuming the undivided shape shown in Plate I, while some may have both forms on the same tree.

III. An ornamental variety of mulberry, *Morus alba*, variety *venosa*. Of no value as food for silkworms.

IV. Leaves of seedling Russian mulberry, *Morus alba*, variety *tatarica*. This mulberry, owing to its extreme hardiness, is used for stocks on which to graft or bud the most valuable varieties in order to perpetuate their characteristics, propagation from seed being altogether unreliable for perpetuating varieties.

V. The native red mulberry, *Morus rubra*. From a specimen in the Herbarium of the U. S. National Museum. The varieties of this species are usually prized for their fruits, being of little value as food for silkworms.

VI. Paper mulberry, *Broussonetia papyrifera*. Valueless in silk culture. A.—Leaf from old tree. B.—Leaf from 2-year-old seedling. C.—Twig with female flowers.

VII. The Persian or black mulberry, *Morus nigra*. This species is cultivated in Europe and Asia for its fruit. From photograph of a tree in the grounds of the U. S. Department of Agriculture.

VIII. Osage orange, *Toxylon pomiferum*. Leaves, fruit, and bark. The mature leaves of this native tree provide excellent food for silkworms.

IX. Summer cuttings of the white mulberry, with leaves shortened to prevent excessive evaporation.

X. Winter cuttings of 1-year old shoots of white mulberry, ready for planting.

XI. Root grafting the mulberry. A and B.—Scions fitted on stocks, ready to be tied. C.—Stock and scion wrapped and ready to be planted.

XII. Scion or sprig budding. This method of propagation can be used on strong seedling stocks or on branches of trees. A and B.—Scions prepared for inserting. C.—Stock with bark raised, ready for scion. D.—Scion in position, ready to be wrapped. E.—Stock with scion held in place by wrapping. F.—Stock waxed to exclude air and moisture.

BRANCH OF WHITE MULBERRY (MORUS ALBA), WITH LARGE UN

Branch of White Mulberry (Morus alba), with Divided Leaves

Branch of White Mulberry. Morus alba var. tatarica (L.)

LEAVES OF SEEDLING RUSSIAN MULBERRY (MORUS ALBA). VARIETY TATARICA.

BRANCH OF THE NATIVE RED MULBERRY (M[illegible])

PAPER MULBERRY (BROUSSONETIA PAPYRIFERA).

A, Leaf from cultivated tree. B, Leaf from two-year-old seedling. C, Twig with female flowers.

BRANCH OF THE PERSIAN OR BLACK MULBERRY (MORUS NIGRA).

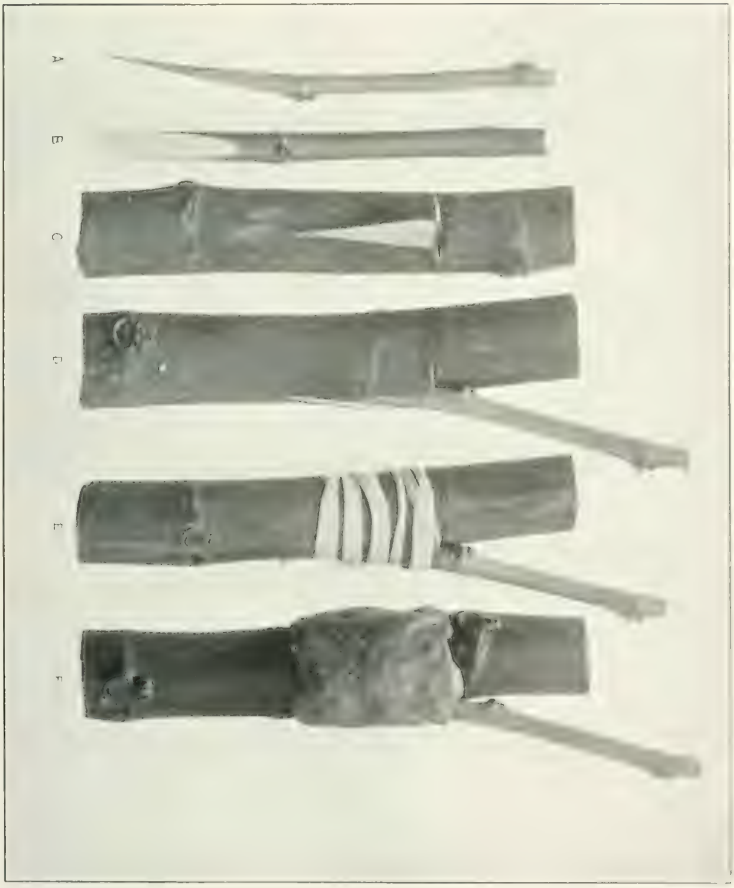
LEAVES, FRUIT, AND BARK OF THE OSAGE ORANGE (TOXYLON POMIFERUM).

SUMMER CUTTINGS OF WHITE MULBERRY, WITH LEAVES SHORTENED.

WINTER CUTTINGS OF ONE-YEAR-OLD SHOOTS OF WHITE MULBERRY, READY FOR PLANTING.

ROOT GRAFTING THE MULBERRY

A and B, scions fitted on stocks, ready to be tied; C, stock and scion wrapped and tied.



SCION OR SPRIG BUDDING.

A and B, scions prepared for inserting; C, stock with bark raised; D, scion ready to be wrapped; E, scion wrapped; F, stock waxed.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF PLANT INDUSTRY—BULLETIN NO. 35.
B. T. GALLOWAY, *Chief of Bureau.*

RECENT FOREIGN EXPLORATIONS,

AS BEARING ON THE AGRICULTURAL DEVELOPMENT OF THE SOUTHERN STATES.

BY

S. A. KNAPP, SPECIAL AGENT,
SEED AND PLANT INTRODUCTION AND DISTRIBUTION.

ISSUED FEBRUARY, 14, 1903.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., September 18, 1902.

Sir: I have the honor to transmit herewith a report on "Recent Foreign Explorations, as Bearing on the Agricultural Development of the Southern States," by Dr. S. A. Knapp, Special Agent, Seed and Plant Introduction and Distribution, and recommend that it be published as Bulletin No. 35 of the series of this Bureau. This report has been submitted by the Botanist in Charge of Seed and Plant Introduction and Distribution with a view to publication.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The introduction of Kiushu rice by the Section of Seed and Plant Introduction of the United States Department of Agriculture in 1899 was the first step taken toward improving the conditions of rice growing in southern Louisiana and Texas, and the marked development of the rice industry since that time is in a large measure due to the value of this variety. There were still other problems connected with the rice industry, however, as well as those which concerned the improvement of extensive tracts of pine lands occurring in many of the Southern States, which remained unsolved. These problems could be best approached by first securing all the information available in foreign lands, and Dr. S. A. Knapp was commissioned to go to Asia to make a careful study of the rice industry and to secure such seeds as he might decide were valuable.

Dr. Knapp's report deals with the life of the peoples among whom he traveled, as well as with the methods and cost of rice production and the cultivation and production of certain other crops, and altogether it constitutes a unique contribution to our knowledge of the agriculture and the condition of the farming communities of these countries.

The report is submitted for publication as Bulletin No. 35 of the Bureau of Plant Industry.

A. J. Pieters,
Botanist in Charge.

Office of Seed and Plant
Introduction and Distribution.
Washington, D. C., September 12, 1902.

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RECENT FOREIGN EXPLORATIONS, AS BEARING ON THE AGRICULTURAL DEVELOPMENT OF THE SOUTHERN STATES.

INTRODUCTION.

The rice belt of Louisiana and Texas comprises a section of prairie land bordering on the Gulf of Mexico and extending westward from the parish of St. Mary, along the coast of Louisiana, 140 miles to the Sabine River, and thence about 400 miles along the Texas coast to Brownsville, on the Rio Grande, with an average width of 60 miles and a mean elevation above the sea level of 6 to 40 feet.

Throughout the entire belt the surface has such a slight variation that for the purposes of irrigation it may be considered practically level. The soil is a rich, sandy loam, in some sections, underlaid with a tenacious clay at the depth of 2 to 3 feet. In the other sections the soil is a strong clay or clay loam, with subsoil conditions similar to that of sandy loam. Between these extremes the sand and the clay form many grades of loams, but all easily tilled and fertile. At a depth of 8 to 16 feet from the surface a stratum of water-bearing sand is generally struck, the water answering for house purposes. At a depth varying from 60 to 250 feet, veins of water providing a flow sufficiently strong for purposes of irrigation have been uniformly found.

This rice belt contains more acres of arable land than any one of a majority of the States in the Union. It is intersected by a large number of navigable rivers and minor streams, and has one of the most salubrious climates on this continent.

Until within a comparatively recent date (1884), however, it was regarded as almost valueless for agricultural purposes, due to its inaccessibility, its generally level surface, and its retentive soil. From an early period an occasional small field has been successfully planted in rice, but this was invariably handled by primitive methods. In 1884 the adaptation of wheat machinery to rice culture began, and with it the rapid expansion of this industry. For nearly ten years thereafter the rice crops mainly depended for success on rainfall, and the rice farmers met with many reverses, though irrigation by the construction of surface canals was undertaken as early as 1890.

By 1898 the canal and the deep-well system of irrigation had been satisfactorily tested and the rice industry was rapidly extending along safe lines. At this point it was found that too large a per cent of the machine-handled rice was liable to breakage in milling. The attention of the U. S. Department of Agriculture was called to this fact, and measures were immediately taken to remedy the defect and to overcome the difficulty by the introduction of new varieties. The Department work resulted in the introduction of a variety from Japan, known as Kiushu, which has given very satisfactory results.

In the evolution of this industry further difficulties became apparent. While rice could be successfully planted during a period of nearly four months—March, April, May, and June—it all ripened at nearly the same time, giving only about one month for harvest against four months for planting; that is, it was demonstrated that the harvest could not be prolonged in proportion to the period of planting, where only one variety of rice seed was used. The varieties planted developed this peculiar characteristic, that whether planted in March or June the crop would mature at about the same time, that planted later developing in every instance with increased rapidity. The harvest is the season of high wages, and the limited harvest period increased the expenses and prevented using the care necessary to properly cure, thrash, and store the crop, thus greatly augmenting the cost and reducing the quality of the rice. If the period of harvest could be materially lengthened, every grower could produce from 50 to 100 per cent more rice than at present. One farmer with a single helper and good teams can prepare the land and plant 200 to 300 acres of rice. It would be difficult to cut more than 100 to 150 acres with the same help, but if the harvest could be extended over three months' time, then the laborers who planted the crop could in the main harvest it. It became evident that this result could be attained only by planting early, medium, and late maturing varieties, and that these varieties must be rices of fixed characteristics and habits of growth. Such, with few exceptions, can be found only in Asiatic countries, where centuries of uniform conditions of climate and culture have established fixed habits of growth in certain varieties of rice.

A second and almost equally important reason for visiting foreign rice-producing countries was to observe methods of cultivation, harvesting, and storing, in so far as these affect the quality of the grain, and, if decidedly beneficial, then to suggest some way by which the same result could be obtained by the use of machinery. It had already been observed by American rice growers using imported Japanese seed rice that it had several points of superiority over the home-grown rice and it was desirable to find the reason for this superiority. (1) It had generally been noted that the vitality and germinating power of the imported seed were nearly 40 per cent greater than that of domestic

seed. (2) That imported seed averaged better in color and was freer from rust than much of the domestic. (3) That it was less liable to be chalky and break under the milling process.

Now, were these conditions due to soil, climate, and selection, or to more careful methods of harvesting and storing? If upon investigation it was decided that they resulted from the latter causes, then it was believed that the machinery used could be modified or added to till the rice grown upon the prairies of Louisiana and Texas would possess every excellence of the foreign article.

It should not be inferred that the rice lands of the United States are limited to the coast prairies of Louisiana and Texas; but in that section rice farming is carried on entirely with machinery, and the peculiar difficulties are more pronounced. The alluvial lands of the Lower Mississippi and of other rivers flowing into the Gulf of Mexico, as well as many tracts in the Carolinas, Georgia, and Florida, are admirably adapted to the cultivation of rice, and growers in these districts are deeply interested in anything that relates to improvements in rice production. Except where the density of population demands the use of all land to meet the food supply, there will be found many untilled tracts in the river bottoms of nearly all of the Southern States which can be profitably utilized for rice. Hence the best methods of producing rice are of general interest.

Other questions receiving the earnest attention of the U. S. Department of Agriculture relate to the vast tracts of land in the Gulf and South Atlantic States which are rapidly being denuded of their pine timber or on which the work of devastation has been completed. Except for some small value they possess as grazing lands they have been held in slight esteem from an agricultural standpoint. As a whole these lands possess a soil almost destitute of humus, with a stiff subsoil and a mechanical condition most unfavorable to the growth of plants. If valuable plants could be found that readily adapt themselves to such conditions, then the pine-land problem would largely be solved. The Department therefore decided to collect from Asiatic countries the most valuable of such plants and to conduct a series of experiments on the pine lands of the South to determine the best methods of making them profitable to agriculture.

JAPAN.

Such marked benefits had been secured by the importation of Kiushu rice that it was considered worth while to find other rices in the Flowery Empire that would ripen at different periods, suited to the requirements of our harvest. Two days spent at the Royal Agricultural College at Kamaba, Tokyo, and one day at Nishigahara Experiment Station gave a comprehensive view of the valuable work along practical and scientific lines for the advancement of agriculture going on

in Japan. Many tests had been made at these stations to determine the varieties of rice most profitable for general use among the farmers of Japan, and samples were exhibited of each variety tested. Fifteen of the best for general planting, including early, medium, and late varieties, were selected. In addition to the samples of seed exhibited, small plats of each variety were shown in the trial fields, from which, in connection with the notes that had been taken, the relative vigor and habit of growth of each variety were determined. Some deductions which the Japanese experimenters have made may be profitably noted here: (1) The great importance of selecting pure-bred seed of even quality and size of grain. (2) The removal of any light or imperfect grains. This is done in Japan by soaking the seed rice in water several days till it is about ready to sprout, when it is thrown into salt water of 1.3 specific gravity and allowed to remain two minutes, being gently stirred meanwhile. The light grains will float; the others are removed, washed in cold water, and planted. When a seed drill is to be used the damp seed is first dried by being rolled in the ashes of rice straw. (3) Even sprouting of the grains is very essential to even ripening of the crop. This is accomplished by previously soaking the seed as above stated.

The agricultural station experimenters found it profitable to use about 200 pounds of superphosphate per acre on rice. They also used with good effect soy-bean cake, horse manure, human excreta, and straw ashes. Too much straw plowed under caused fermentation and injured the roots of the plants. For their conditions the fertilizer should contain nitrogen, phosphoric acid, and potash in the ratio of 2, 1.5, and 1.2.

It is the observation of scientific and practical men in Japan and China that the best rice can not be produced on low, marshy ground. Such rice is relatively dark in color and inferior in quality. The best rice is produced on well-drained land. It is claimed that one advantage of planting a rice field to a winter wheat or barley crop is that the soil is dried and pulverized.

By the time the fields of growing rice had been carefully examined and the subject fully discussed with Japanese farmers, the 15 varieties originally selected were reduced to 10 by elimination of the less valuable ones. At Kobe some additions were made to the list on the advice of E. H. Hunter, the well-known rice miller, and the final number of varieties selected for importation was 15. This seed arrived in the United States in good condition and has been planted for trial. If it meets expectations the Department will be prepared to distribute seed which has been fully tested.

AGRICULTURAL SITUATION.

The following account of agriculture and rural life in Japan may be of interest: Rice forms the principal article of food of the Japanese,

and its cultivation presents many interesting problems. First, about 45,000,000 people must be sustained largely by the product of 7,000,000 acres of rice. This allows nearly 6½ persons to the acre and on the basis of the crop of 1896 furnishes 4 bushels of hulled rice, or about 240 pounds of milled rice, for each person. This indicates that Japan has attained a density of population which allows only a narrow margin between home consumption and possible production.

ACREAGE AND YIELD OF FOOD CROPS.

It must not, however, be inferred that rice is the sole food of the people. The daily ration includes a variety of foods of a highly nitrogenous character, which, with vegetables, supplement the rice. The following official report of the number of acres of food crops produced annually in Japan will correct to some extent the impression that the Japanese subsist almost solely on rice:

Food crops of Japan, as reported for 1896.[a]

Food crops.	Acres.	Total product.	Product per acre.
		Bushels.	*Bushels.*
Rice[b]	6,967,461	180,938,855	26
Wheat	1,104,200	17,763,915	16.09
Rye	1,681,267	14,608,117	8.7
Barley	1,626,260	39,246,425	24.1
Peas and beans	1,343,191	18,063,070	13.4
Millet, buckwheat, and rape	2,077,982	28,002,330	10.6
Irish potatoes	57,790	6,862,469	118.75
Sweet potatoes	195,251	68,402,579	350.33

[a] This does not include Formosa.
[b] The statement regarding rice refers to this product with hulls removed, and for comparison with paddy about 20 per cent should be added.

The acreage devoted to rice in Japan can not be very much increased. The islands are of volcanic formation, and in a general way it may be stated that a rather bold range of mountains traverses them from the southwest to the northeast, occupying seven-eighths of the territory. The remaining one-eighth consists of fertile valleys, widening toward the sea until they gradually expand into coastal deltas of considerable extent. The narrow valleys are terraced on each side; at the base of the mountains canals are made to receive the descending rivulets and convey the water to the various fields as required for irrigation.

Frequently the surplus water is used to turn an overshot wheel for milling rice or for manufacturing purposes in the native villages, or it may be allowed to flow into some creek or river, but as far as possible sufficient mountain water for irrigation is conducted by canals at a level somewhat higher than the rice field. (Pl. I, fig. 1.) The ingenuity displayed in devising the elaborate system of irrigating canals

and the amount of patient industry required to construct them are simply marvelous. The extent of the retaining walls constructed to prevent the washing of the terraces, or to arrest mountain slides, or as barriers against a river bent on destroying a field, is inconceivable. These are the works of a patient and industrious people throughout many generations.

Occasionally water for irrigation is elevated from a creek or river, but almost invariably by the simplest machinery, such as has been employed for hundreds of years. One of the simplest machines for elevating water in common use is a wooden wheel 6 to 8 feet in diameter and 12 inches wide, with buckets on the perimeter, or rim. The power that raises the water is the weight of a man traveling on the buckets on the side of the wheel opposite the buckets lifting the water. It is so adjusted that the weight of the man on one side of the wheel is a little more than the weight of the water raised by the buckets on the other side; hence the wheel revolves. When the water reaches the required elevation it is discharged into a spout.

METHODS OF RICE CULTURE.

Rice production in all oriental countries is conducted upon the same general plan, but the methods differ so materially from those employed in the United States that they should be carefully noted. The lands are divided by levees into small fields. These are of no regular form, and generally the inclosing levees are gracefully curved to represent some ideal of beauty in the mind of the planter. In the small valleys among the mountains these curved embankments were doubtless necessary to conform to the mountains and thus to inclose a larger area, but as the improvements encroached upon the lowlands curves continued to be used. The levees vary in width from 1 foot for field divisions and paths to 4 feet wide for main embankment roads. This system of levees and fields has precluded the use of domestic animals in the preparation of the soil and harvesting of the rice. The Japanese are fully aware of the disadvantages of having such small and irregular fields, and have made strenuous efforts to relieve the situation.

Many of the rice fields in Japan average scarcely more than 35 feet square, and the boundary levees have such wavy lines that they look as if made by hogs in a frolic. Under modern conditions the horse and the ox could be used in tillage, but there are no paths which such animals can traverse to these minute fields; and if there were, the tracts are too small for the use of plow or harrow, because there is not room to turn, much less to follow the angular boundary lines. If a farmer owns several tracts it is seldom that they are adjacent, and hence he is helpless to institute reform. Many progressive Japanese farmers have tried to institute reforms, but under the old law changes in land boundaries required the unanimous consent of the owners,

which it was practically impossible to secure. This was precisely the situation of the lands belonging to the yeomanry of England until about the commencement of the Nineteenth century. Three years since a law was passed by the Japanese Parliament that if two-thirds of the owners of a tract of land agreed to reform the boundaries the minority must concur. Still the farmers of Japan were conservative, and only two or three provinces have made any considerable progress.

The accompanying diagrams present a striking example of the land situation and the reform accomplished in one locality.

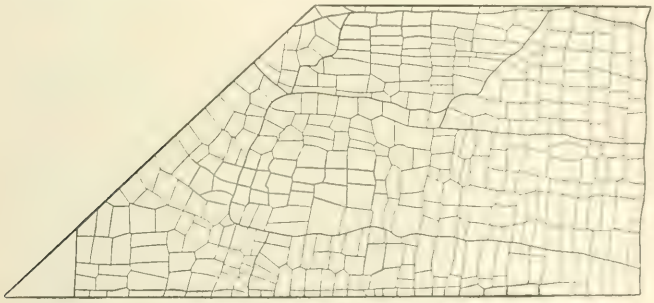

FIG. 1.—Tract of land at Masuda, containing 25 acres, divided into 409 irregular fields.

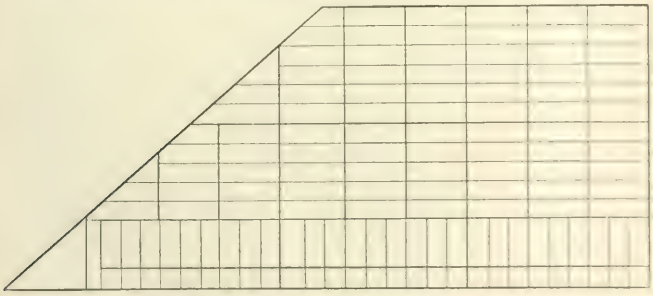

FIG. 2.—The same tract shown in fig. 1, redivided into 138 regular fields.

Fig. 1 is a plat of a tract of land at Masuda village, near Sendai, and shows the little fields as they have been for ages. Fig. 2 is of the same tract readjusted under the reform movement. Mr. J. H. De Forest, of Sendai, who furnished the maps from which these illustrations were made, states that this tract as platted contains only 25 acres and formerly had 409 irregular fields in it. (See fig. 1.) There are now (see fig. 2) only 138 regular fields, with perfectly straight water courses and roads wide enough for two loaded carts to pass. Even

thus enlarged these fields are small indeed as compared with those in the United States, but it is a great advance for Japan.

Such reform as this will greatly facilitate the use of cattle in plowing the wet fields and in carting out the crops. But, more than this, the area of arable land is greatly increased by breaking down the numerous grass ridges and throwing their space into productive soil. About one-tenth is thus gained, or 2 acres in the plat figured; and as 1 acre averages about $175 in value, the entire gain is over $350. But the whole expense of this reform was only $400, so that it almost paid for itself in the value of new space gained, to say nothing of the lessening of manual labor.

Japanese farmers are beginning to see that American methods must be more and more considered if they are to keep pace with agricultural advance all over the world.

FIELD WORK.

The fields of the Japanese farmers are generally well drained and thoroughly tilled, mostly with the spade or mattock. Both of these implements differ from those used in the United States. The mattock has a blade about 16 inches long and 5 inches wide, with a handle 4 or 5 feet long. The implement weighs 7 or 8 pounds. With a quick, powerful blow the blade is driven into the soil about 14 inches; then, using the handle as a lever, the soil is disintegrated and partially inverted. The spade is a wooden blade about 2 feet long with an ordinary handle; the lower end of the blade is cased with steel, and upon the back of the upper end is a block the width of the spade. The spade is thrust into the soil by the foot at an angle of about 30°, and, using the block for a fulcrum, the soil is rolled to one side, as in plowing, but it is more thoroughly disintegrated. All the trash, straw, or grass upon the field is turned under, together with such an amount of lime, ashes, fish manure, or human excreta as the farmer may be able to secure. Where a winter crop is raised the manure is generally applied in the fall. If the rice field remains fallow during the winter the manure is applied at the time of spring working, in March or April, according to conditions.

The seed bed is prepared as early as convenient in the spring, about April 1, thoroughly manured, and is given the care of a bed in the garden. It is spaded 8 inches deep and worked until the manure is thoroughly incorporated and all clods pulverized, after which it is surrounded by a low ridge and water is admitted to fill the soil until the spaded earth becomes consistent mud. The seed, which had been previously selected for purity, size of grain, and flinty character, is then soaked in pure water till well sprouted, which usually requires two days, and is then sown on the bed broadcast as thickly as admissible for strong plants. Prior to sowing the bed is covered with water

to the depth of 2½ inches. In five or six days the rice is well started. It is then left dry in the daytime and is flooded at night. Covering with water at night keeps it warm, and allowing the bed to become dry in the daytime admits air and prevents sun scalding, which frequently occurs when the rice is young and the covering of water is shallow.

Early in June, when the rice is 8 or 10 inches high, it is pulled up, tied in bundles of 6 to 10 plants, and transplanted into fields, which have been prepared and flooded to the depth of 1½ to 2 inches. (Pl. I, fig. 2.)

The rice plants are set in rows about 1 foot apart and at a distance of 10 to 12 inches in the row, on the richest lands, making 9 bunches to the yard. On poor lands double that number might be set. They are so set that the soil covers the root. Thereafter the flow of water is not continuous. After a few days it is drawn off, and if the farmer is able to make the investment an application of rape-seed oil cake or fish scraps is made to the surface. As soon as the fertilizer has had time to become incorporated with the soil, water is again applied and withdrawn to allow the crop to be hoed. Every weed is cut out, and in some cases the roots are slightly pruned. Each field is given the minute attention of a garden. When the growing period is well advanced the water is allowed to remain permanently upon the field, care being taken to renew it by gentle inflow and escape, till a slight change in color indicates that the period of ripening is approaching. It is then withdrawn. While the slight change of color is given as the guide, the time when the milk in the seed has become dough is more correct, for the Japanese cut their rice when the straw is scarcely turned. Both the straw and the rice are better when the harvest occurs before the grain is dead ripe.

CUTTING RICE.

The grain is cut close to the earth, with a small sickle-like knife set in a handle. Four hills or bunches are bound together with two straws, making a bundle 3 or 4 inches in diameter. These are generally laid crosswise in small piles, and are allowed to dry during the day. At evening they are hung with heads down on bamboo poles, which, by means of cross sticks, are made into a structure like a fence. The lower pole is high enough to allow a space of about a foot between the suspended bundles and the ground. The upper pole is 18 to 20 inches above this, the rice bundles on the upper pole overlapping the bundles below. After the bundles hang upon the poles long enough to become dry they are taken down by women and the grain removed by drawing the heads through a hatchel.

The grain is then placed upon mats and exposed to the sun till thoroughly dry. Before it is sent to market the hulls are removed by

passing the grain through a pair of burrs made of cement and bamboo and worked by hand. Winnowing is done by the open-air process, or by a simple fanning mill. (Pl. II, figs. 1, 2.)

After winnowing the milled product is placed in sacks deftly made of rice straw, each sack holding about 133⅓ pounds. In these the rice is transported to market and the sacks are afterwards sold for paper material.

MANURE.

The extent to which night soil is used for fertilizing is scarcely conceivable. Whether in city or country, it is practically all saved in earthen receptacles and removed once or twice daily, according to the weather. The night soil is carried in wooden buckets, balanced on a pole across the shoulder. In cities the collectors sell to fertilizer companies what a man can carry (about 8 gallons) for 10 cents in silver. The companies transport it on flatboats to the rural districts, where it is applied in liquid form. In one corner of almost every garden and field may be found a cistern for storing liquid manure.

FARM WAGES.

Common laborers on the farm in Japan receive on an average 6 cents (gold) per day for women and 10 cents for men, with board, except in harvest time, when they are paid about double these amounts. Harvesting is expensive, considering the price of labor. On one occasion while in Japan a field was passed where two men were cutting rice. They stated they were paid 2 yen ($1 gold) for cutting, binding, and hanging on poles the rice in a small field by the roadside. On measuring it there was found to be two-elevenths of an acre, the cost being at the rate of $5.50 (gold) per acre. Still, it is difficult to see how there could be any change in the methods of managing the rice industry in Japan. The present system of transplanting insures the best results and allows time to take off the winter crop. By the hand process the straw, which is quite valuable, is preserved, the grain is cut at the right time, even where there is a variation of maturity in the same field, and there is no loss from the cracking of kernels by the hatchel.

COST OF RAISING RICE.

A farmer near Tokyo furnished the following data in regard to the profits of rice farming, the estimate being for 1 acre of land:

CASE 1.—Where the owner of the land hires the work done:

Cost of seed, 16 sho, or nearly 36 pounds	$0.62
Cost of manure	10.00
Cost of labor, 120 days' work	18.00
Cost of repairing tools	1.20
Taxes, Government and local	8.00
Profits	16.18
Total	54.00

INCOME.

Hulled rice, 8 koku, or about 2,520 pounds, equivalent to 3,272 pounds of paddy or 20½ barrels	$48.00
Straw, 480 kwan, or about 2 tons	4.80
Chaff and broken rice	1.20
	54.00

Case 2.—Where the land is rented to a tenant, supposing the crops to be the same, the account would stand as follows:

Seed for 1 acre	$0.62
Manure	10.00
Labor, 120 days, at 15 cents per day	[illegible]
Repairing tools	[illegible]
Rent, one-half the crop, or 1,260 pounds	24.00
Total expenses of tenant	52.82
Total profit	[illegible]
	54.00

Total income, $54, as above.

The foregoing statement, taken from the account book of a practical Japanese farmer, is full of interest and throws some side lights on their agricultural system.

The small amount of seed used is due to transplanting. Considerable expense is incurred for manure, but a crop of 20½ barrels per acre is large for old land. One is chiefly impressed by the number of days' work, one hundred and twenty, expended on 1 acre, and the amount of the Government taxes, $8. Eight hundred dollars taxes on a hundred acres of rice would stagger the American farmer. Where the tenant does the farming it will be noted that one-half of the grain produced is allowed for the use of the land and that there is no real profit. He simply receives pay for his labor.

FARM LIFE.

How the Japanese farmers live can best be understood by giving a description of some particular farmhouse. While visiting the distinguished statesman, K. Mochizuki, at his country estate, a visit to the dwellings of some of his tenants was made. The following is a description of an average farmhouse on this estate:

In the rear of the house was a garden of about half an acre, planted to field crops, beans, barley, etc., and in front was a garden of about one-fourth of an acre, artistically laid out and planted to vegetables, with occasional flowers. The main building was one story high, about 24 by 48 feet in size, with the kitchen, 14 by 24 feet, across one end. Here was the usual clay stove, similar to those of Mexico, and a dirt floor, which by some process had been made as hard as cement. The remainder of the house was floored with mats. The family stores were packed in tubs, of which there were a dozen or more stacked at one side of the kitchen, all scoured to appear as if just brought from

the shop. The farmer's wife was cooking at the stove. On the left of the kitchen, in front of the house, was a room 10 by 12 feet, covered with the customary mats and used for a sitting room. Each mat was 3 by 6 feet in size and 2 inches thick. Back of the sitting room and opposite the stove was a room, 10 by 12 feet, used for a dining room. Beyond the sitting room, in the front of the house, was a private room, 12 by 16 feet, for lodging. From the dining room a hallway extended to and along the end of the house. The partitions of the rooms, which are generally removed during the day to give more ventilation, were made of light sash, with strong white paper instead of glass. On the right of the kitchen was an addition, 20 by 24 feet, for the servants' quarters and general storage. Each servant had a small sitting room and a lodging room, with mats on the floor. There was no furniture, as we use the term, in the house; no chairs, tables, bedsteads, or mirrors. The members of the household sit, eat, and sleep on the matted floor. How everything can be kept so perfectly clean, without soil or stains, belongs to the mysteries of Japanese housekeeping. In front of the servants' quarters a servant was cleaning grain and spreading it on the mats to dry in the sun. The tub and pounder for cleaning rice was in front of her. She did not like to be photographed in her ordinary garb, but was satisfied when told to turn her back and appear to be at work.

Adjoining the house on the left was a beautiful Japanese garden or tiny park, possibly 40 feet square, containing the usual landscape, trees, and statuary. In the center of this park and about 20 feet from the farm dwelling stood an artistic little one-story house, about 14 by 16 feet in size. It looked like a large playhouse for children, but we were informed that this was a special house for receiving guests and serving tea. The Japanese paper windows were slid back, revealing a beautiful little parlor about 10 feet square, with the usual seat or bench of honor on one side, and a tiny waiting room. The house was a frame building, cross lathed and plastered, with posts exposed, boarded up and down on the outside, and ceiled overhead. In the rear of the house was a barn, 18 by 20 feet.

The house here described is a typical Japanese farmhouse, one story, with thatched roof. The laborers' cottages are built upon the same plan, but are smaller. The residences of wealthy country gentlemen are somewhat larger and with more elaborate grounds, but they retain the same simple arrangements and general style of living. There is no arrogant caste in Japan. The rich and the poor, the landlord and the tenant, the employer and the employed, live on the most intimate and friendly terms.

Among the farmers of Japan, rice is considered quite a luxury and many can not afford to eat it regularly. Among the poorer farmers barley, millet, and sweet potatoes are substituted for rice. Among the

better nourished Japanese the following constitutes the ordinary bill of fare: Boiled rice, boiled rape and daikon (half radish and half turnip), bean soup, and barley tea for breakfast and dinner. Lunch at noon is the same without the bean soup. A little salt fish is added occasionally.

GENERAL REMARKS.

Japan has an area of 147,655 square miles, exclusive of Formosa, about one-tenth of which, or 15,000 square miles, is tillable. The population is now not far from 45,000,000, which gives a ratio of 3,000 persons to the square mile of arable land. At this ratio the State of Iowa could sustain 156,000,000 people and Texas more than 600,000,000. This statement is sufficient to refute the claim that Japanese agricultural products may at some future time compete with America in our home markets. Japan is rapidly becoming a great manufacturing and commercial nation, for which she is, by virtue of the genius of her people, exceedingly well adapted. The trend of events indicates that when that time arrives Japan will be a large consumer of American food and fiber products.

CEYLON.

The island of Ceylon, a British dependency, in latitude 6° north, contains 25,365 square miles and has a population of 3,391,443, composed of about two-thirds Cingalese and one-third Tamils, with a few Moormen and Malays. The Cingalese are the primitive inhabitants and occupy mainly the southwestern portion of the island. They are medium sized, well formed, rather light colored, intelligent, and dignified. They are inclined to play the gentleman even in the roughest work, but are honest and make good clerks. The Tamils have been imported from the mainland, presidency of Madras, and bear a striking resemblance to the American negro. They do a large part of the farm work and furnish most of the servants. There is not, however, much general farming done in the island, the central portion of which is occupied by mountain ranges, though the valleys are fertile. Only about 4,400 square miles are under cultivation of any kind. The thin sandy soil of the coast does not appear to be adapted to any crops except the cocoanut palm, which grows with amazing luxuriance, and the nuts constituting an important article of export. In the higher lands and on the mountain sides are large plantations of tea and coffee, with occasional groves of cinnamon and other spices.

AGRICULTURE.

Rice is the main crop, but not enough of this is produced for home consumption, large quantities being imported from Penang, Singapore, India, and Burma. When preparing the ground for rice, a kind of

wooden drill, shod with iron and drawn by oxen or water buffaloes, is used. Two crops are produced, of which the principal or maha crop is sown in July, just in time to catch the late summer rains, and is harvested in December or January. The small or yala crop is planted in February and harvested in June. About 15 bushels per acre is considered a fair crop on the west coast, but in Anuradapura Province 30 to 50 bushels per acre are frequently obtained, depending on conditions. The Ceylon rice is rather inferior in quality.

IMPORTS.

The imports of cleaned rice at Colombo, Ceylon, from January 1 to November 10, 1900, were 486,652,390 pounds; from January 1 to November 1, 1901, 459,229,540 pounds. This shows that Ceylon, with a population of about 3,500,000, imports more rice than the entire product and annual imports of the United States.

FARMHOUSES.

The farmhouses are one story generally, with about three rooms, and are commonly built of brick or sun-dried clay, with mud-plastered walls. Some houses are built of poles, lathed with bamboo or bamboo matting, and are plastered with clay outside and inside. The floors are of tile or clay, and the roof is covered with grass, palm leaf, or tile. The usual cost of a house is $50 gold. Farm laborers receive about 8 cents (gold) per day, without board, but generally prefer to work for a share of the crop. One-half is given to the laborer. (Pl. III, figs. 1, 2.)

INDIA.

India (including Burma) has an area of 1,800,258 square miles and a population a little short of 300,000,000. This population is not uniformly distributed. It is very dense in the valleys of the Ganges, the Brahmaputra, and the Indus and its tributaries. Bengal, with an area of 151,543 square miles (less than three-fifths of Texas), has a population of about 75,000,000.

TIMBER.

The absence of timber in India strongly impresses the traveler. No fences, rarely woodlands, and no barns in a country almost exclusively devoted to agriculture indicate a peculiar people. In the government reports considerable forest lands are mentioned. They are, however, in remote sections and quite inaccessible as a source of supply of wood and timber for the centers of a dense population. The price of wood for fuel is from $16 to $40 per cord and not very good wood at that; hence the masses must live without fire, except the little that is used for cooking.

EXTENT OF ARABLE LAND.

The large proportion of the whole country that is arable is one of the first and most noteworthy observations of the traveler in India. In Japan one-tenth of the entire area can be tilled, and in China a large part of the country can never be subjected to the plow, although China as a whole ranks high in fertile lands; but in India, out of the 544,993,122 acres of surveyed land in 1899, seven-elevenths were available for cultivation and 196,487,658 acres were actually sown with crops.

FERTILITY OF THE SOIL.

One of the most suggestive items to be noted is the fertility of the soil, after a tillage of so many thousand years, with little manure of any kind. With few exceptions all the dung of animals is used for fuel, and as far as observed those exceptions were limited to the government farms. Many good farmers are said to use some cattle excreta on the land, but in all the small villages visited dung, made into patties and dried in the sun, was almost the only fuel. In the vicinity of cities the preparation and sale of cattle dung for fuel is quite an industry, and as far as observed it is all used in this way.

GREEN MANURES.

Inquiry at all the government agricultural stations visited and observations throughout India failed to develop a single case where green manures had been used to fertilize the soil. A further evidence that it is not used is found in the fact that the plows used simply stir the soil, but can not turn anything under.

COMMERCIAL FERTILIZERS.

It is difficult to use commercial fertilizers among Hindu farmers, for they suspect that all such preparations contain bone, blood, or some refuse of dead or slaughtered animals, and they declare it will defile them to handle it. An English gentleman in Calcutta told me that he had purchased some commercial fertilizer for his garden and his Hindu gardener refused to put it on the land. He employed a low-caste man to apply it to the vegetables, and after it was applied the gardener made no objection to working the soil on which it had been scattered.

CROP ROTATION.

Rotation of crops is well understood and practiced. This gives a partial relief in case of continuous cropping. To some extent summer fallowing has been employed as a renovating method. On the whole the present fertility of the soil is marvelous.

PUBLIC ROADS.

The main highways are models of excellence, broad, well graded, and bordered with lovely shade trees, such as the banyan, the tamarind, and the sacred neem. At suitable distances wells have been made, and near them are located rest houses for weary travelers. Generally the rest houses are unfurnished and without any resident care-takers, but all day and all night they are occupied by weary travelers for a shorter or longer rest, as the case may be. Here and there may be seen a single man or woman; but generally the people travel in families or small groups, carrying their more cumbersome bundles upon their heads and their wealth upon the ankles of their women in the form of silver bangles.

Mingled with the country people are numerous pack oxen and donkeys, with immense loads of all kinds of products. The oxen are noted for their docility and the donkeys for their diminutive size, being not more than 30 inches tall; but they are sturdy little animals and for their size they carry enormous loads.

CONVEYANCES.

In addition to the native families and village groups traversing the principal highways, there may be seen numerous carts drawn by oxen with a peculiar hump on their shoulders, the straight yoke resting on their necks and tied firmly to their horns. The carts are crude affairs. In some cases the wheels are merely two thicknesses of 2-inch plank, crossing each other at right angles, while in other cases the wheel consists of a large hub through which spokes are mortised to support a wooden felly 5 or 6 inches deep and 5 inches wide.

The carts invariably have large wooden axles, which soon wear the hubs and allow the wheels to stand at considerable angles. Occasionally a native official or the family of some village headman rides in an ekka or a tonga drawn by a trotting ox.

DRESS.

The clothing of the country people is exceedingly simple. In warm weather the men wear a turban and a single loin cloth so wrapped as to form a sort of breeches, extending to the knee; generally they have neither shoes nor sandals. In cold weather the cotton loin cloth is supplemented by a thick cotton bedquilt worn like an Indian's blanket. The women wear short skirts and a thin cotton waist without sleeves, and in addition a long shawl or wrap of thin cotton stuff is thrown over the head and twined about the shoulders or allowed to hang loose.

COUNTRY HOUSES.

There are no country houses, in an English sense, in India. The ryots (farmers) live in a collection of dwellings called a village for

want of a better term. These houses are of one story, having a single room, or occasionally two. In the mountain regions the walls are of stone, while on the plains they are made of brick or dried mud. There is usually a small yard in the rear of the house. There are openings, but no windows, and the doorway, if closed at all, simply has a bamboo-mat curtain. The roofs are made of tile and the floors of clay hardened by repeated washings with cow dung.

VILLAGES.

Between the houses in the small villages are narrow, tortuous alleys, but rarely regular streets. The village is surrounded by a high wall of stone, brick, or adobe, which answers for a fence against depredators, the cattle being brought within this inclosure at night. Each village has its customs and unwritten laws, and it and not the individual is the political and social unit. It has its blacksmith and carpenter, its doctor, and its headman or chief, and generally its banker.

The government taxes for the village are paid by the headman, who assesses them among the inhabitants in proportion to their property or income. Local matters are settled by the village, though in important cases there lies an appeal to the British courts. The village doctor, the carpenter, and the blacksmith are paid in rice at the harvest, not for specific work done, but as a sort of annual salary.

PLOWS AND SCRAPERS.

The plows used in different provinces vary somewhat, but have a general resemblance in that there is no moldboard and the instrument is simply one for stirring the soil. It consists of three pieces—the standard, the tongue, and the steel drill at the tip of a wood support or shoe. (Pl. IV, fig. 2.)

The standard is usually 3 by 4 inches and about 5 feet long, into which, about 12 inches from the lower end, the tongue is mortised at an angle. The standard stands a little less inclined than ordinary plow handles. Near the upper end is a single pin used for a handle. A steel bar about 1 inch square at one end and brought to a point at the other passes through the lower end of the standard and is supported by a V-shaped shoe. This steel bar stands at such an angle that the sharp point penetrates the soil 3 or 4 inches or more, as may be required. It amounts to nothing more than a sharp-tooth drill, and costs 60 cents complete. This plow is drawn by two oxen. (Pl. IV, fig. 1.) In use, the steel tooth cuts from the land a cloddy strip from 4 to 6 inches wide, and this is then broken up by the wedge-shaped wooden shoe. Afterwards men and women pass over the fields and smash the lumps with their mauls. Some ryots use a crude clod crusher made of wood and drawn by oxen. The harrow is much like ours, but crude. After the harrow has been used the routine of labor depends upon the crop to be planted.

In some cases where the farmers were planting wheat they used a wood scraper to prepare wide, flat furrows for the seed. This scraper consists of a board 1 by 6 inches and 3 feet long, with a handle 4 feet long attached to one edge at the center. The lower edge of the board is sharpened. It requires two men to operate it—one holding it on the ground by means of the handle and the second standing about 8 feet in front and pulling it from the holder by means of a rope. In this slow way a shallow furrow is formed for the water of irrigation. (Pl. V, fig. 1.) It must not be inferred from the inferior implements used that Indian lands are not well tilled; the farmers make up for the defects of tools by additional labor.

SEEDING AND HARVESTING.

Seeding is done in a variety of ways, one method being for the dropper to follow the plow and drop the seed into the drill-like furrow through a tube behind the plow, the next furrow covering it. Or the seed may be sown broadcast and harrowed. Or, in case of rice, the plants may be set into the flooded field from a seed bed previously prepared. The grain is all hand cut, and when dry, thrashed by tramping with oxen.

RICE FARMING.

The experience of the practical and scientific farmers of India has shown that rice does best on a deep clay or clay-loam soil, but the subsoil should not be so stiff as to prevent all natural drainage and cause stagnation of water, since rice is more luxuriant where fresh water is constantly added. Sandy-loam soils, if manured, produce an excellent quality of rice; the more manure the better the rice. More seed per acre should be used on sandy-loam soils than on clay loams.

Rice sown late in the spring when the weather is hot requires more seed than if sown in the early spring. If sown in a seed bed and transplanted the least seed is required—about 35 pounds per acre. Drilled rice requires about double this quantity, and if broadcasted 15 to 20 pounds more per acre are needed than when drilled.

While there are many hundred varieties of rice, for practical purposes only three general classes need be recognized, i. e., early, medium, and late ripening.

TREATMENT OF THE SEED BED AND MANURING.

The site for the seed bed is usually selected on land more or less elevated to insure drainage. If water is allowed to stand on the field between crops it produces a ferment which is unfavorable to the future production of the plants.

The use of green stable manure on rice fields just before planting is not recommended. It is of little value, due to the fact that where ordinary manure is kept very wet it undergoes no chemical changes by

which useful plant food is liberated. Therefore manure should be well rotted and applied long enough before planting to have some effect; better still, in case of a winter crop on the same field the manure should be applied to the winter crops. It is a common practice after plowing to burn trash on all seed beds from which rice plants are to be transplanted. Coarse grass, dead leaves, brush, rice husks, straw tramped under the feet of the oxen, dust piles, and occasionally some cattle dung are piled on the plowed land, and on top of this a thin layer of soil is spread to prevent rapid burning. The trash is then fired. The effect of this on the seed bed is the production of an ash for the support of the young plants and the destruction of weed seeds and injurious roots near the surface. The action of the heat on the surface soil also tends to liberate potash and phosphoric acid and to make the soil more porous.

PLOWING AND FERTILIZING.

Plowing and other heavy field work are generally done by bullocks, water buffaloes, or camels. Great emphasis is placed on repeated plowing. In India most of the rice lands receive no manure and have not received any for centuries, yet they continue productive, and when well tilled yield fair crops. One writer states: "All that is necessary to produce a bumper crop is timely and abundant rain." Some writers seem to think that the fertility of the rice lands of Bengal is due to the overflowing of the Ganges and Brahmaputra rivers. But these streams do not overflow and deposit silt to the same extent that this is done by the Nile. Moreover, this would not explain the fertility of the terraced rice land. The continuous fertility can not be due to the use of manure, for practically no commercial fertilizers are used, and almost all the droppings of cattle are used for fuel. It is mainly due to great natural strength of soil, good tillage, and rotation of crops.

METHODS OF CULTIVATION.

In December the old straw and trash are raked into pil and burned on the land. The field is then plowed, and at intervals it is given two more plowings, after which it is left until the latter part of March or early part of April, when the clods are crushed, and advantage is taken of the first rains to plow it twice more. The field is harrowed after each of the later plowings. Harrowing is done with a ladder having pins on the under side. The cultivator rides on the ladder, which also serves in a measure to break the clods. When the rice is up a few inches it is raked. This stirs the soil and to some extent thins the plants. The average product of a field sown and cultivated in this way is 6½ barrels per acre.

Where rice is sown in a bed or nursery and transplanted into the field, the field is first plowed three or four times in water, thoroughly

mixing the soil into thin mud. After the mud has settled the ground remains covered by about 2 inches of water. Where the fields depend on rainfall for moisture the plants are transplanted during a shower. The plants are set in hills 6 inches apart each way, two or three plants being set in each hill. In this way about 28,000 plants are set per acre. Transplanting for the main or aman crop is done in May, and for the spring or boro crop in December and January. It is possible in some parts of India to raise five crops of rice in one year. The first crop is called aus and is the summer harvest from July to August; the second crop, or kaida, from September to October; the third, chatan aman, from October to November; the fourth, called boran aman, from December to January, and the fifth or boro crop from April to May.

In the sub-Himalayan districts labor is very cheap, and it is customary to dig over the fields for rice with the mattock to the depth of 6 inches. This costs 80 cents per acre.

PRODUCT PER ACRE.

It is difficult to arrive at any correct estimate of the yield per acre from direct statements by native farmers. By dividing the total product in a given season by the total number of acres planted it has been ascertained that the average yield of rice per acre for all India is 823 pounds for the principal crop and 558 pounds for the spring or boro crop, making 1,381 pounds, or about 8½ barrels, for the year, as only two crops in one year are generally raised. This is not a large showing for two crops, and it is quite evident that if one crop should be raised and the land devoted to green-manuring crops the remainder of the season, the one rice crop for the year would exceed the amount at present secured from two crops.

HARVESTING.

Rice is cut with a small sickle or hook knife and bound at first in bundles about 3 inches in diameter. After it has cured a while, the small bundles are made into larger ones and drawn to the thrashing place, where they are placed in hollow stacks, one tier of straw deep, with the heads on the inside. Twenty women can on an average harvest 1 acre in a day. One binder, four horses, and two men in the United States daily do the work of two hundred women in India.

THRASHING.

The usual mode of thrashing is to clear and level a small space of ground, wash it with cow dung until hard, and to pile on this circular form the rice to be thrashed. Five bullocks are tied to a rope tandem, and driven around on this pile of unthrashed grain. Sometimes, to expedite the work, a second line of bullocks is used. Two men drive the two lines of bullocks and two men sift the straw with forks. In this way four men and ten bullocks will thrash the grain from an acre

in six hours. When the straw is to be kept whole the rice is thrashed by beating the heads over the edge of a plank.

During the harvest and thrashing time the farmer has to be constantly on the watch to see that the paddy is not stolen by dishonest laborers. He frequently builds a straw hut close to the thrashing floor in which he can sit and sleep. It is a regular custom to surround the pile of paddy with a ring of ashes so that it can not be approached without evidence.

WAGES.

Money wages are not usually paid. In some cases the reaper gets 1 load out of every 21 he cuts. In other cases he gets 10 or 12 pounds of paddy for a day's work. Usually he receives 6 pounds of paddy and half a pound of cleaned rice. Laborers are generally employed by the year, and the wages paid are much less than the above, averaging about 2 cents per day. The ordinary plan upon which crops are raised is to form a farmers' club. For this purpose five to ten farmers, each the owner of a pair of bullocks and a plow, form a club to help each other plow their lands.

COST OF CULTIVATION.

The ryot never keeps any account of his expenses, and hence it is difficult to estimate the cost of cultivating an acre of rice; but allowing customary wages and estimating the time required for the work performed, the following is an approximation of the cost on an acre of land where rice is sown broadcast:

Plowing 4 times, 12 days' work for 1 man and a pair of bullocks, at 3 cents per day	.60
Carrying and spreading manure, 4 men 1 day	.08
82½ pounds seed paddy	.32
One plowing and harrowing after seeding, 3 teams 1 day	.08½
One weeding, 20 women 1 day, at 2 cents	.40
Repairing levees, 16 men 1 day, at 2 cents	.32
Reaping, 16 women 1 day	.32
Carrying the bundles of paddy to the thrashing place or floor	.04
Thrashing, 4 men and 10 bullocks 1 day, at 2 cents for each man and 1 cent for each bullock	.18
Cleaning and winnowing, 3 men 1 day	.06
Rent of first-class land per acre	.80
Additional charges per acre	.12
	3.24½
Yield of first-class land, 1,010 pounds of paddy, valued at	3.84
Profit per acre	.59½

The foregoing estimate, obtained from the most reliable authority, is impressive because it shows the low condition of agriculture in this Himalayan district. The wages of a man one day—2 cents—and the charges for the use of an ox one day—1 cent—are prices below our conception of values of labor.

It is noted that no account is made of manure and straw. Very little manure is generally used, and in many districts none. In the interior, where the above estimates were received, the straw and manure have no commercial value. While wages are low the price of rice is also low, only 32 cents for 82⅔ pounds of paddy, or 61½ cents per barrel of 162 pounds. When the rice crop is handled in the usual way—the plants grown in a seed bed and transplanted to the field—there is an additional cost of 6½ cents for preparing the seed bed; and the cost of pulling plants and transplanting into the field, which requires five men and twenty-eight women one day, is 66 cents. There is, however, a saving of 40 cents for weeding and also a saving in spreading manure and other small items, which reduces the total cost of an acre of transplanted rice to 30 cents more than that of broadcast, leaving a net profit of 29½ cents per acre on the crop.

In the above estimates no account is made of the Government assessments on rice, which are considerable. These are sufficient at least to wipe out all profits in this class of farming.

The following estimates of the cost of raising rice under high-class conditions are furnished by Hon. James Mollison, inspector-general of agriculture for India:

Preparing and tilling seed bed		$0.64
Manure used on seed bed, 6 loads; on an acre, 20 loads		4.16
Cost of seed, 80 pounds		.80
Plowing, puddling, and leveling		1.52
Transplanting		.80
Weeding seed bed		.48
Top dressing with castor cake, 200 pounds per acre		.96
Cutting, thrashing, and winnowing		1.44
Tying and stacking bundles of straw		.24
Cost of irrigation		1.28
		12.32
Add Government tax per acre		4.80
Total cost per acre		17.12
Probable crop, 3,000 pounds, valued at	$24.00	
Value of straw	1.60	
		25.60
Net profits per acre		8.48

The above estimates are based on wages in the Surat district, which are higher than in the Himalayan, but still very low.

Under good cultivation the cost per acre is equal to that in the United States.

NORTHERN LIMIT OF CULTURE.

The question is frequently asked how far north rice can be produced profitably. Hon. C. L. Dundas, director of agriculture for the Punjab, stated that he could not tell, but assuredly as far north as his administration extended, 34° 15′ north latitude.

CONSUMPTION OF RICE AS FOOD.

The people in India do not keep account of farm products, except as they are compelled to by law; hence it is impossible to arrive at any exact data except through Government sources. In some provinces of India rice is the principal food; in others, less rice is produced and it constitutes only a portion of the food supply. In Bengal the 75,000,000 people on an average consume 1 pound of rice per capita each day, or 365 pounds per year, as determined by the Government reports. This would appear to be large, but in the way this amount is obtained it covers all losses, wastage, etc. The following table gives a comprehensive statement of the food crops produced in India and the relative proportion of rice to other grains:

TABLE 1.—*Area (in acres) under crop of principal products in each province of British India, 1897–1900.*

[Native States not included.]

Province.	Rice.	Wheat.	Barley.	Millet.	Corn.	Peas, beans, pulses, etc.
Upper Burma	1,818,962	15,813	120	804,950	76,300	195,523
Lower Burma	6,277,678	14	.....	718	11,492	15,010
Assam	3,653,583	223	59	.....	2,823	86,284
Bengal	39,656,800	1,541,400	1,448,200	183,500	1,802,200	5,111,200
Northwest Provinces	4,592,603	4,601,392	3,154,323	3,395,313	1,143,139	3,945,395
Oudh	2,899,792	1,619,583	1,020,830	547,575	462,575	2,224,635
Ajmer-Merwara	296	1,838	27,214	91,109	62,138	14,240
Parganá Mánpur	167	1,292	.....	2,504	1,101	509
Punjab	482,795	5,488,598	898,443	1,243,605	1,239,723	1,047,568
Sind	898,853	347,445	8,910	1,014,678	1,400	165,678
Bombay	1,251,143	811,590	44,328	11,035,141	184,854	1,861,980
Central Provinces	4,708,624	1,633,777	6,005	80,887	104,201	2,921,605
Berár	44,138	21,192	234	60,102	[illegible]	[illegible]
Madras	6,429,045	20,636	3,318	4,155,425	[illegible]	[illegible]
Coorg	94,423	.....	.....	18,750	[illegible]	[illegible]
Total	[a]72,808,952	[b]16,104,793	6,611,984	22,633,756	5,195,472	23,348,758

Province.	Sugar cane.	Cotton.	Jute.	Total acres in crops.	Total population.
Upper Burma	2,236	153,734	.....	2,976,850	3,167,791
Lower Burma	9,330	9,068	.....	6,335,106	4,693,103
Assam	28,315	3,399	100,168	3,743,078	5,433,668
Bengal	873,000	144,000	1,970,500	51,733,900	70,434,425
Northwest Provinces	1,023,851	968,502	.....	24,444,459	33,801,894
Oudh	235,326	28,780	.....	10,176,896	12,650,831
Ajmer-Merwara	190	35,453	5	199,478	345,258
Parganá Manpur	16	1	.....	[illegible]	[illegible]
Punjab	360,978	735,125	.....	11,074,831	20,861,061
Sind	2,615	91,091	.....	2,488,277	2,871,774
Bombay	70,515	2,050,251	.....	15,964,219	15,145,927
Central Provinces	25,733	712,856	.....	12,129,278	10,784,294
Berár	2,471	2,061,082	.....	3,097,782	2,897,040
Madras	58,638	1,382,716	.....	20,694,679	35,630,410
Coorg	[illegible]	[illegible]	.....	[illegible]	[illegible]
Total	2,693,023	[c]8,375,841	2,070,673	164,878,789	.....

[a] Total yield, 618,966,312 barrels of 162 pounds each. [b] Total yield, 246,240,500 bushels.
[c] Total yield, 2,110,562 bales of 400 pounds each.

In the more populous provinces the area planted to food crops is so small in proportion to the population that even the slightest failure results in disaster.

Nearly all the tilling of the soil is done with the plow, and oxen, buffaloes, and sometimes cows furnish the motive power. The small number of carts (wagons are not used on the farms) is explained by the fact that a large part of the transportation of produce is done on the backs of oxen or donkeys.

TABLE 2.—*Area (in acres) irrigated in British India, 1899–1900.*

Province.	Irrigated from—		Tanks.	Wells.	Other sources.	Total irrigated.	Net area cropped during year.	Area cropped more than once.
	Government canals.	Private canals.						
Upper Burma	252,161	307,198	129,864	7,211	102,587	799,021	3,695,206	260,036
Lower Burma	310	1,325	.....	.....	3,434	5,069	6,857,898	846
Assam	.....	.....	.....	.....	.....	.....	4,552,210	565,146
Bengal	754,557	.....	.....	.....	.....	754,557	53,253,600	10,618,100
Northwest Provinces	1,981,373	5,692	1,215,683	4,478,507	553,595	8,234,850	24,402,658	4,461,342
Oudh	.....	.....	976,394	1,643,178	80,453	2,700,025	8,624,254	2,427,975
Ajmer-Merwara	.....	.....	7,228	43,776	116	51,120	230,773	17,400
Parganá Mánpur	.....	.....	.....	324	.....	324	6,786	136
Punjab	4,243,524	823,729	20,049	4,154,598	134,083	9,375,983	23,275,728	2,017,570
Sind	2,352,433	140,595	.....	41,005	110,414	2,644,447	2,781,014	215,474
Bombay	99,829	5,013	30,413	667,789	78,149	871,223	19,278,203	320,293
Central Provinces	.....	810	176,187	64,118	14,079	255,264	14,762,603	164,340
Berár	.....	72	.....	66,838	107	67,017	5,403,758	1,495
Madras	2,648,160	26,289	1,832,527	1,129,804	146,986	5,783,766	23,122,215	2,674,229
Coorg	1,370	.....	.....	.....	.....	1,370	200,117	701
Total	12,333,717	1,310,723	4,388,345	12,297,148	1,224,003	31,544,036	190,447,023	23,745,083

Table 2 shows the number of acres irrigated as in Table 1, native states not being included. Of course lands subjected to natural overflow or on which there is a heavy rainfall are not included in this table. The irrigated lands are principally planted to wheat and food crops other than rice, although in some provinces the rice crop depends entirely on artificial irrigation. In the best rice districts, however, the rainfall is very heavy, amounting to over 200 inches in a year in Lower Burma, which with the annual deposits from the overflow of the Irawadi River makes it ideal rice land.

Table 3 shows the number of head of live stock and number of farm implements in the same area as that covered by Table 1.

TABLE 3.—*Live stock and farm implements in British India.*

Province.	Bulls and bullocks.	Cows.	Buffaloes.		Sheep.	Goats.
			Bulls.	Cows.		
Upper Burma	687,823	697,939	109,953	98,581	5,113	25,043
Lower Burma	578,821	397,338	276,620	231,588	2,374	12,374
Assam	1,102,938	1,006,305	91,136	[illegible]	[illegible]	[illegible]
Bengal	1,195,736	880,751	105,597	[illegible]	[illegible]	[illegible]
Northwest Provinces	7,045,630	4,567,777	565,835	[illegible]	[illegible]	[illegible]
Oudh	3,148,842	2,065,569	219,357	866,232	[illegible]	[illegible]
Ajmer-Merwara	64,390	60,233	2,731	21,142	[illegible]	[illegible]
Parganá Mánpur	1,996	2,009	27	727	[illegible]	[illegible]
Punjab	4,631,729	2,566,047	592,137	1,903,070	[illegible]	[illegible]
Sind	528,744	515,559	5,502	190,093	[illegible]	[illegible]
Bombay	2,295,836	1,139,843	197,780	669,469	[illegible]	[illegible]
Central Provinces	2,831,655	2,524,616	354,531	511,467	[illegible]	[illegible]
Berár	697,791	623,370	37,909	211,771	[illegible]	[illegible]
Madras	4,411,350	3,853,408	846,679	1,560,104	8,234,262	5,181,629
Coorg	34,629	26,674	11,931	7,690	629	1,755
Total	29,257,910	20,927,441	3,417,725	9,133,896	17,932,237	19,059,649

Province.	Horses and ponies.	Mules and donkeys.	Plows.	Carts.	Young stock and buffalo calves.
Upper Burma	23,197	2,692	415,630	239,101	698,724
Lower Burma	12,112	[illegible]	478,388	199,181	594,034
Assam	9,908	133	821,570	11,883	1,390,561
Bengal	35,913	12,722	458,211	60,337	246,227
Northwest Provinces	434,426	262,777	3,162,668	486,136	6,408,351
Oudh	181,084	50,213	1,464,406	100,702	2,427,824
Ajmer-Merwara	2,436	5,029	33,069	9,407	21,040
Parganá Mánpur	83	23	865	315	1,111
Punjab	312,746	612,387	2,229,768	242,648	3,712,614
Sind	76,799	84,442	213,042	45,125	352,797
Bombay	90,367	51,207	891,451	468,958	1,550,191
Central Provinces	94,542	17,628	1,295,953	117,521	1,886,250
Berár	29,627	20,488	136,041	129,779	249,549
Madras	40,239	120,086	2,749,701	524,041	4,383,459
Coorg	101	274	26,979	715	19,086
Total	1,343,880	1,240,101	14,407,742	2,925,849	25,882,111

WELLS.

The wells are open, 5 to 7 feet in diameter, and 30 to 60 feet deep. On one side of the well an embankment is made about 5 feet high. This slopes at an angle of 20° from the well and frequently terminates in a pit a few feet deep. This embankment forms a descending road for the oxen to travel when hoisting the water. A bullock's hide is used for a bucket; the corners are attached to a rope, which passes over a single pulley at the top of the well and is tied to the yoke of the oxen. Each hoist carries about one barrel. (Pl. V, fig. 2.) Two yoke of oxen are required, as one yoke can be used only six hours consecutively, and there must be one man to drive the oxen, one to

manipulate the bucket, and one in the field to distribute the water. Three men and four oxen will water 10 acres of wheat during the cropping season.

RICE PRODUCED.

In 1900 there were in the provinces of Bengal, Burma, and Madras 49,915,913 acres in rice, which produced 435,822,000 barrels. If we place the product of the remaining 22,893,039 acres in rice at 183,144,312 barrels, the total for India would be 618,966,312 barrels of rough rice, or about 177 times more than the entire rice product of the United States.

AGRICULTURE IN THE PUNJAB.

Hon. C. L. Dundas, director of land records and agriculture for the Punjab, stated, in reply to inquiries, that—

Unirrigated rice can only be grown in the submontane tracts, where there is heavy rainfall. The average yield is about 550 pounds per acre. On irrigated lands the average yield is about 900 pounds. A good crop would be 1,200 pounds, and 1,500 can be obtained by careful cultivation. In the Punjab this is produced almost invariably by owners with small holdings. If the holding is large, part is cultivated by the tenant on the share plan, the tenant paying one-fourth to one-half the gross product. Hired labor is employed sometimes in transplanting and generally in harvesting. This is paid for in kind.

Throughout the Punjab, women of the agricultural class are employed in the lighter kinds of outdoor field labor, such as harvesting, picking cotton, etc. The women of certain tribes of high social or religious character never work in the field, but generally women work on the lands of their male relatives. Compensation consists in their food and a small present in kind at the close of the harvest, practically subsistence and nothing more, but differing from the starvation wages of civilized countries by the patriarchal customs of India, which forbid a man from filling his own stomach while leaving his employee hungry. Hence harvest wages depend entirely on the harvest. If this is good, the laborer, male or female, may get enough grain to keep him or her two or three months. Unless forced by famine, women will not work in the field except for their male relatives. In the Himalayas the women do all the farm work, including plowing.

Windmills being unknown and water mills impossible on the plains, all the grain used as food in India is ground on handmills (small stone burrs) by women. Spinning is universal, and much of the coarse cloth used for clothing is manufactured at home.

The cost of labor necessary to produce a crop of rice is about 45 per cent of the total product grown, including the straw. To give a definite cash estimate of cost is practically impossible. A landlord would, in a typical case, pay some 8 per cent customary dues and divide the balance with his tenant, paying one-half his own share in water rates and land revenue to the Government. The revenue or tax to the Government varies from $1.50 to $3 per acre. As a rule, the landlord works his own farm.

The highly flavored rices are regarded as choice, but the people prefer to plant the coarser varieties, as giving less trouble. There is apparently great obscurity in the scientific names of rices, and it is difficult to distinguish varieties.

Wheats, millets, and gram (peas) form the staple crops, wheat being the chief article of export. Considerable cotton is produced. About 110 pounds of lint cotton is an average crop for an acre. It sells at about 5 cents per pound.

The practice of plowing under renovating crops I believe is unknown in the Punjab. Cattle for plowing or lifting irrigating water range in value from $15 to $25 per head. Buffaloes are worth from $20 to $35 per head and camels about $15 each. The price of cattle for work varies with the provinces. At Poona a good buffalo for field work is worth $6.50; an ox $16 to $17. At Delhi a buffalo is worth $8 to $10; an ox $16 to $26, according to size. Native plows generally sell for 60 cents each.

COST OF LIVING.

Among the ryots no cash estimate of the cost of living could be obtained. The following statement made by an educated Hindu may be assumed to be correct as regards cost of living in the city: A laborer needs 1 pound of rice, worth 2 cents; one-half pound of dahl (split peas), 0.75 cent; one-half pound of barley, 0.875 cent; condiments, 0.17 cent; fuel, 0.5 cent; making a total of 4 cents for a day's living. Better living for laborers earning higher wages costs about 6 cents per day, divided as follows: Rice, 1 pound; mutton, one-half pound; barley, one-half pound; vegetables, condiments, oil or butter, and fuel. The retail price of rice, low grade, is here given at 2 cents per pound. The wholesale price in India for this grade is about 1 cent per pound and in Burma 90 cents per hundred.

RICE FARMING IN LOWER BURMA.

Rice farming in Lower Burma varies somewhat from that in Bengal. The lands are richer, and the rains are more abundant. The cultivator commences to plow about the 1st of June and continues to work the soil till he secures an even surface of mud, which is kept soft by the heavy rains. In July women transplant the rice from the seed bed and receive for this work at the harvest a certain number of bundles per hundred plants set. The harvest commences in November, and cutting, curing, thrashing, and winnowing are done in much the same manner as in Bengal. Rice cultivation in Lower Burma comes nearer being on a commercial basis than in India. Wages are regulated by each village and are frequently paid in money. Laborers who are imported from Madras in harvest time usually receive 23 cents per barrel of product for cutting and binding. A large portion of the crop is cultivated on the tenant system, the landlord furnishing land and seed every other year and receiving one-third to one-half the product. He furnishes no house nor other buildings and does not fence the land. A yoke of cattle will work about 10 acres of land.

RICE MILLING.

Very little rice milling, as the term is commonly understood, is done in India proper, except for resident Europeans. In the rural districts, where the rice is wanted for local consumption or for export, the hulls are removed by pounding, using a pounder worked by the foot. Pounding and winnowing in the open air or by a fanning mill

complete the milling process. There is no charge for milling, the hulls and bran being considered by the natives full compensation. As late as 1891 there were only two modern power mills in India. Most of the rice exported to Europe from Bengal is cargo rice, four-fifths husked and one-fifth paddy. It is claimed by shippers that cargo rice is not as liable to heat on shipboard as that completely milled. In Burma the grower markets all his rice in the paddy and in bulk, except such as goes by rail, which must be sacked. The larger part is delivered by boat, and is carried to the mills in baskets by coolies. It is weighed and delivery actually takes place in the mills. At first the mills were merely husking mills to prepare the large crop of paddy for export, but gradually other processes were added until complete modern milling plants were equipped. The hulling stones in the best mills are made of emery. Some of the machines are cruder than similar machines in the United States, but they appear to do the work satisfactorily. Permission was freely granted to inspect the Kemendine mill in Rangoon, which has a daily milling capacity of 500 tons of rice for native use or 300 tons for Europeans. A larger mill has just been completed for the same company. The Kemendine does no custom milling. The paddy is bought and the milled product sold on the market. There are over fifty mills in Rangoon, and many of them do custom work. The usual price for custom milling ranges from $2\frac{1}{4}$ to $3\frac{3}{4}$ cents per bushel, or an average of 11 cents per barrel, giving the farmers all the by-product. The breakage in milling for native use amounts to $6\frac{1}{4}$ pounds per hundred. For European use or for export rice milling the charges are 18 cents per barrel. The laborers employed are mostly Tamils from Madras, who are paid from 24 to 32 cents per day. Women employed in the rice mills are paid 12 to 16 cents per day. Most of the mills use the hulls for fuel. Over 24,000,000 barrels of paddy rice were milled last season at Rangoon for foreign account. This furnished a large amount of bran and polish, which the thrifty Chinese in Burma and the Straits Settlements buy and feed to pigs and cattle. Many mills are owned by Chinese. Last year Burma furnished about 2,000,000 tons of cleaned rice for export.

RICE FOR FOREIGN MARKETS.

India and Burma rice is not generally raised on a commercial basis. Each farmer or tenant produces enough for home consumption, and the surplus is sold for whatever it will bring. If the price falls ever so low just the same amounts are produced and placed on the market. It is true that if rice is abundant and cheap in India home consumption is increased. Rice is raised in those countries commercially very much as eggs are generally produced in the United States. No account is kept of the expenses, and it is sold regardless of cost. Where no cash wages are paid it is impossible to determine the cost of production.

American supremacy in the rice industry depends upon more economical production. This may be accomplished by diversified farming and by an increased efficiency in machinery. Improved machinery in the rice field is of recent introduction, and it will undoubtedly be made more efficient and the rice farmers will handle it with greater economy.

SELECTION OF SEEDS.

No rices were seen in India that appeared to be an improvement on those grown in the United States, except possibly some very early varieties. In Bengal there are varieties that mature in sixty days. While it must not be expected that they will mature as quickly in America, they are nevertheless worthy of trial on account of their rapid maturing qualities.

India produces some good wheats and shows a large and profitable yield in the latitudes corresponding to our Southern States. Out of 150 varieties 5 were selected as worthy of trial. A few good soil-renovating plants were found. The sunn hemp (*Crotalaria juncea*) is highly recommended by the Poona State Farm for its luxuriant and rapid growth. If planted immediately after the rice harvest, it will make a growth of 2 feet before frost. Some valuable sorghums and vetches for the semiarid portions of the United States were found.

CHINA.

In scholarship, energy, and business qualities the Chinese take very high rank among the nations of the earth. They are bright, apt, of indefatigable perseverance, and instinctively grasp the financial bearings of business transactions. They soon become the merchants and bankers of every country in which they settle. They have such marvelous tact along business lines that Europeans doing business in China uniformly employ Chinese agents or compradors in all dealings with the Chinese.

AGRICULTURAL CONDITIONS.

It is difficult to deal with the agricultural conditions in China in a comprehensive way, because there are no reliable statistics published, and the traveler is limited to his observations and the very meager information to be obtained from Chinese farmers. The farmer, too, is not disposed to give information to a stranger, thinking that some advantage will be taken of it. In traveling through the rural districts of China the large areas of unused lands were observed with surprise. Along the Yangtze in particular the cultivation of the highlands has been largely abandoned and tillage has been limited to the fertile alluvial lands. Even in the vicinity of Nankin, the old capital of the Ming Dynasty, there are thousands of acres of land, evidently fertile if properly tilled, which lie neglected as commons. The rainfall is

somewhat uncertain on the highlands and it is necessary to resort to irrigation, but apparently an abundance of water for most food crops can be obtained from wells. These highlands bear evidence of having been cropped in former ages.

Few nations are in advance of the Chinese in economic production and in crop results along well-established lines of agriculture, but they seem to be entirely ignorant of modern methods of renovating worn-out soils. Thousands of acres of land in the vicinity of large cities, it was said, could be obtained of the Government either free or at a nominal cost for renovation and cultivation.

The almost entire absence of timber or woodlands in eastern China was noted with surprise. The highlands and the mountains are completely denuded, with the usual result of alternate periods of great drought and excessive rainfall. Grass and reeds are used for fuel. During September thousands of men and women were cutting grass from the sides of the mountains, coarse grasses in the untilled places in the valleys, and the tall reeds on the Yangtze bottoms. These were bound into bundles and sold for fuel. In cooking with this trashy material one person is needed to feed the fire. In cities a common fuel is coal dust, mixed with equal quantities of clay, made into balls about 3 inches in diameter and dried. The Government does not appear to be making any effort to restore the forests.

An impressive feature of Chinese rural life is the apparent insecurity of person and property. Every farmer has a compound, or high-walled inclosure, into which stock is driven at night and in which are stored the farm crops. Farmhouses of the better class are about 42 feet square, and without windows in the outside walls. In the center of each house is an open court, generally about 14 feet square, called the "heavenly well," which admits air and light to the rooms. The houses of the coolies or peasants are rarely more than 16 by 24 feet in size and contain one room only, having no compound. Pigs and chickens are driven into this room at night. The houses are one-story structures with adobe, brick, or stone walls, according to the cost of material, with thatched or tiled roofs and clay or tile floors. There are no fences; consequently the farm animals are herded.

TILLAGE OF THE SOIL.

In some provinces there is considerable hand tillage after the manner of the Japanese, but generally oxen, cows, or buffaloes are used for plowing. The plows are much like those used in India. They operate like a single-tooth harrow slightly depressed from the horizontal, and simply stir up the ground. No inversion of the soil is possible. On the alluvial lands water buffaloes are generally used for plowing rice fields, because they are plowed with water standing on them and worked until a field of mud is secured. After the first plowing, high

lands, especially such as are used for gardens, are worked over with a claw hoe, the tines of which are 8 to 10 inches long. This is forced into the ground by a quick, smart stroke, and the tool is then pulled toward the cultivator. Steel-toothed harrows are also used to pulverize the soil.

Plowing for rice is done in May. Seed beds are prepared and planted in April, and about the 1st of June the young rice plants are transplanted from the seed bed to the field. To prevent breaking the roots a spade is run under the plants some 2 inches below the surface before pulling commences. The plants are set in rows which are 8 inches apart, the space between the plants in the rows being about the same distance. After the plants are set out the field is kept flooded with water about 2 inches deep till the heads begin to fill. Further irrigation is then left to the rainfall unless it is unusually dry.

IRRIGATION.

One of the common ways of irrigating gardens is from open wells, using the balance pole and bucket to raise the water. For raising water only a few feet a narrow vertical wheel is used and operated by the weight of one or two men opposite the water to be elevated and sufficient to balance it. For higher lifts a large wheel is commonly used, with wooden or earthen buckets on the rim. Oxen turn a horizontal wheel, which imparts power to the vertical wheel by means of cogs in the rim.

CULTIVATING, HARVESTING, AND THRASHING RICE.

The Chinese are good cultivators. They go through the rice fields pulling all the weeds and stirring the soil with their fingers or with a small rake. When the rice is ripe it is cut with a small reap hook, bound into bundles, and set up in small shocks. Thrashing is done by whipping the heads over the edge of a box some 6 feet square. The rice is then spread on mats in the sun to dry.

HULLING RICE.

Before the rice is sent to the market it is generally hulled by pounding, using the foot-power pounder so universal in the Orient. If complete milling is required, the pounding is continued longer. Occasionally the hulls are removed by placing the grain in a small circular stone trench, in which a broad-rimmed wheel is rolled by ox power. A long axle passes through the wheel, one end of which is attached to a pivot in the center of the space surrounded by the stone trench, and the other extends some 6 feet beyond the wheel and trench; to this end the oxen are attached and are driven around till the rice is hulled.

PRODUCTION AND COST OF MILLING RICE.

The average yield of rice is from twenty to thirty fold. This probably denotes a crop of 1,200 to 2,000 pounds of paddy. The cost of milling is 7½ cents (gold) per barrel (162 pounds), of which 6 cents is paid for pounding and 1½ cents for winnowing. The entire cost of milling is met by the value of the bran and hulls. The red rice and lower grades are all consumed locally. The local price of rice is from 1 to 2 cents per pound, according to quality. It is difficult to secure accurate data, because in the different provinces weights of the same name vary materially in the amount they represent and coins of the same denomination differ in value.

COST OF BUILDING, ETC.

Hard brick sell for $2.10 per thousand and it costs about $1.50 per thousand to lay them in a wall. The wall is the principal expense incurred in building in the country. Lumber for building is generally imported from the United States and is expensive, costing on the coast from $40 to $80 per thousand. Country carpenters and masons usually receive 10 cents per day and board. Farm laborers are paid $5 per year and board. Board for a day consists of 1¼ pounds of rice, costing 2 cents, and pork and vegetables costing 1 cent. Allowing 10 cents per month for the labor of cooking the food, the total cost of board is about $1 per month.

EXPORTATION OF AGRICULTURAL PRODUCTS.

There is no probability of the overproduction of staple foods in China and their large exportation for the following reasons:

(1) At present China produces only about sufficient food for her own consumption; any large increase of the area planted would involve a system of levees to protect river bottoms, and deep wells to irrigate the highlands.

(2) Before rice and other grains can be produced in large quantities for export, the Chinese must feel that they are safe in the enjoyment of their property, and the duties between different provinces and the petty exactions imposed on internal commerce must be abolished. The conservative type of Chinese character prevents radical and sudden changes. The increasing consumption will keep pace with the increase of production.

THE PHILIPPINE ISLANDS.

A visit to the Philippine Islands in October, 1901, confirmed the opinion formed during a visit in 1898, that from an agricultural standpoint these islands are among the most valuable territories of all Asia.

This does not mean that the soil is richer than portions of Japan, China, India, or Siam, but richness of soil is not the only element that determines productive capacity; rainfall and temperature, with good drainage, are even more essential conditions than natural richness of soil. In possessing a uniform temperature suited to the best conditions of tropical plant growth, the Philippines enjoy a great advantage. The distance of the islands from China and Siam is sufficient to allow the intervening water to neutralize any chill winds from the northwest, while the great warm current of the Pacific touches them upon their eastern shores, producing a most enjoyable climate. The rainfall, from 80 to 100 inches per annum, is sufficient to meet the requirements of tropical plants; but what is still more important, it falls during the months—May to December—best suited to the growth of plants. This is followed by a comparatively dry period—December to May 15—in which the plants mature and are harvested.

The report of the observatory at Manila shows the following average number of days in each month on which rain fell:

Rainfall in the Philippine Islands.

Month.	Number of days on which rain fell.	Rainfall.[a]	Month.	Number of days on which rain fell.	Rainfall.[a]
		Inches.			*Inches.*
January	4.3	1.15	August	10.8	13.08
February	2.2	.47	September	20.7	15.02
March	3.4	.65	October	14.4	7.47
April	3.5	1.11	November	11.3	4.92
May	9.2	4.2	December	8.4	3.69
June	15.4	9.68	Total	125.7	75.56
July	22.1	14.72			

[a] The rainfall is the average from 1865 to 1896, inclusive.

The following table, compiled from the report of the observatory at Manila, shows the mean temperature of each month for seventeen years ended 1897:

Temperature of the Philippine Islands.

Month.	Temperature.	Month.	Temperature.
January	77.0	August	[illegible]
February	77.9	September	80.6
March	80.6	October	80.4
April	[illegible]	November	[illegible]
May	[illegible]	December	[illegible]
June	82.4		
July	[illegible]	Average	80.[illegible]

The valleys are broad and well drained, while the mountains are approached by a gradual elevation and frequently by table-lands, and are generally fertile to the top. Neither on the coast nor in the lowest valleys of the interior is the heat at any time oppressive, and within a short distance from any point on the islands it is possible to reach an altitude where the climate is perfectly delightful, even in the warmest season of the year.

RANGE OF PRODUCTS.

Taking all the islands and the fertile mountains into consideration, there is possible a very wide range of products, from the most delicate spices to the hardy cereals. The chief commercial products have been rice, sugar, tobacco, coffee, and fiber plants, but the islands can produce cattle, wheat, corn, oats, the legumes, and the grasses.

STOCK AND PASTURE LANDS.

Like Porto Rico, the Philippines furnish admirable conditions for stock raising. The mountain sides have frequent streams of pure water and produce an abundance of grasses, somewhat coarse and lacking in flavor, but which if cropped closely are relished by domestic animals. Softer and sweeter grasses can readily be introduced. Bermuda grass and several of the Paspala and some clovers do well. Stock raising has been profitably carried on for many years by natives, often on quite a large scale. The native horses are small, but are hardy and of immense energy, showing their descent from Andalusian stock. There is a good demand for dairy products, and few lines of husbandry would be found more profitable.

FODDER PLANTS.

The soil and climate of the Philippines are especially adapted to the production of a great variety of fodder plants. Among the many may be mentioned alfalfa, esparcet, serradella, vetch, lupine, pea, soy bean, *Lespedeza bicolor*, *Pueraria thunbergiana*, *Astragalus latoides*, cow peas, *Panicum colonum*, guinea grass, and *Panicum maximum*. During the rainy season it would be necessary to use these plants for soiling, as the almost daily showers prevent curing. From December 1 to May hay could be made in most parts of the islands.

SUGAR CANE.

Conditions are very favorable for raising sugar cane. The heavy rainfall during the growing period, followed by the dry months of December, January, February, March, and April, are ideal conditions, so far as climate is concerned. This gives a full year for growth and five months for manufacturing the sugar. The sugar mills are very

crude, except some in Negros, Panay, and Cebu. In Luzon the sugar factories are mainly of the open-kettle sort, and with machinery cruder than is generally used in farm sorghum manufacture in America. Some stone rollers for crushing the cane are used, and many factories have only large wooden tubs with iron bottoms for boiling the cane juice. In Panay and Cebu the mills are of a higher type, although crude as compared with American up-to-date milling plants. (Pl. VI, fig. 2.)

RICE FARMING.

The method of raising rice in the Philippines is practically the same as in India, except that the plowing is almost exclusively done with water buffaloes, and a larger proportion of the land is sown broadcast. Rice planting is usually done in June, and harvesting in November and December. Only one crop is raised each year. With artificial irrigation two crops could be produced annually, one in the summer and one in the winter and early spring. The area devoted to rice could be considerably enlarged, but it is doubtful whether in the evolution of the islands under American conditions such will be the result, as a number of other farm products are more profitable and are cultivated with less labor. The natives much prefer to plant and work manila hemp (*Musa textilis*), as when once planted it produces a crop for several years with slight attention. Coffee and some of the spices are favorite products in certain sections. Plowing the land and setting rice plants in the mud is a disagreeable task, even to Filipinos; consequently the general trend of agricultural industries in case of expansion will be away from rice and toward crops more easily handled and more profitable.

FRUITS.

Nearly every known variety of fruit can be produced on these islands, from such as require extreme tropical conditions to the hardy fruits of the temperate zone, like the apple and the cherry, for the islands possess a great range of climate. There are valleys where the temperature never falls below 70° and there are table-lands where it drops nearly to the frost line in the winter. These extremes are found on the same island. At Manila 65° F. above zero would be extraordinary weather. A hundred and thirty miles north, in the province of Benguet, the grains and fruits of northern New York can be produced.

TIMBER.

It is estimated that only about one-fifteenth of the land has been brought under cultivation. A large portion of the remainder is timber land, and nearly all of it belongs to the Government. Many very

valuable varieties are found, among which is mahogany. Except the teak forests of Upper Burma, now under complete Government control, these are the most valuable timber lands in eastern Asia, and if cutting is properly regulated they will remain a source of profit for many years. At present the only method of obtaining this wood is to cut and hew it into square timbers, which are then dragged down the mountains by oxen. By this method fully one-third is wasted and many valuable young trees are destroyed.

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FIG. 1.—RICE MILL AMONG THE MOUNTAINS, JAPAN.

FIG. 2.—PLANTING RICE, JAPAN.

FIG. 1.—CLEANING RICE, JAPAN.

FIG. 2. POUNDING RICE, JAPAN.

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FIG. 2.—SUGAR-BOILING HOUSE, LUZON.

CROSS SECTION OF A DYING TREE OF THE BULL PINE, SHOWING BLUE COLOR

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 36.

B. T. GALLOWAY, *Chief of Bureau.*

THE "BLUING" AND THE "RED ROT" OF THE WESTERN YELLOW PINE, WITH SPECIAL REFERENCE TO THE BLACK HILLS FOREST RESERVE.

BY

HERMANN VON SCHRENK,

SPECIAL AGENT IN CHARGE OF THE MISSISSIPPI VALLEY LABORATORY.

VEGETABLE PATHOLOGICAL AND PHYSIOLOGICAL INVESTIGATIONS.

ISSUED MAY 5, 1903.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture.
Bureau of Plant Industry.
Office of the Chief.
Washington, D. C., December 24, 1902.

Sir: I have the honor to transmit herewith a technical paper on The "Bluing" and the "Red Rot" of the Western Yellow Pine, with Special Reference to the Black Hills Forest Reserve, and respectfully recommend that it be published as Bulletin No. 36 of the series of this Bureau.

This paper was prepared by Dr. Hermann von Schrenk, Special Agent of this Bureau in Charge of Timber Rot Investigations, a line of work being conducted jointly by this Bureau and the Bureau of Forestry, and it was submitted by the Pathologist and Physiologist with a view to publication.

The illustrations, which comprise 14 full-page plates, several of which are colored, are considered necessary to a full understanding of the text.

Respectfully,

B. T. Galloway.
Chief of Bureau.

Hon. James Wilson.
Secretary of Agriculture.

PREFACE.

The report submitted herewith, entitled The "Bluing" and the "Red Rot" of the Western Yellow Pine, with Special Reference to the Black Hills Forest Reserve, covers in part an investigation undertaken by the Bureau of Plant Industry in cooperation with the Bureau of Forestry in the broad field of the diseases of forest trees and the means of controlling them, as well as the causes of and methods of preventing the decay of all kinds of timber, especially that valuable for construction purposes. At the present time an immense quantity of dead and dying timber of the bull pine is standing in the Black Hills Forest Reserve, South Dakota. The amount has been variously estimated, but will probably approach 600,000,000 feet. The death of the trees was caused by the pine-destroying beetle of the Black Hills, as shown by investigations conducted by the Division of Entomology of the United States Department of Agriculture.[a] Following attack by the beetles the wood of the tree is invaded by various fungi, one of which causes the blue coloration of the wood. Dr. von Schrenk has demonstrated, however, that the fungus which causes the bluing does not injure the strength of the wood.

The rapid decay or "red rot" of the timber is caused by another fungus, and its ravages can be forestalled by a proper use of the wood. A series of recommendations is made, which, if followed, will result in the saving of a very large part of the dead wood.

ALBERT F. WOODS,
Pathologist and Physiologist.

OFFICE OF THE PATHOLOGIST AND PHYSIOLOGIST,
Washington, D. C., December 23, 1902.

[a] Bull. 32, n. s., Division of Entomology, U. S. Dept. of Agriculture, 1902.

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THE "BLUING" AND THE "RED ROT" OF THE WESTERN YELLOW PINE, WITH SPECIAL REFERENCE TO THE BLACK HILLS FOREST RESERVE.

INTRODUCTION.

The present investigation was undertaken to determine—

(1) The cause of the blue color of the dead wood of the western yellow pine, commonly known as the bull pine (*Pinus ponderosa*), and the effect of the coloring on the value of the wood.

(2) The reason for the subsequent decay of the wood, the rate of decay, and whether the decay could be prevented.

(3) Whether it would be possible to use the dead wood before it decayed; first, to reduce the fire danger; second, to prevent the decay and thereby save an immense quantity of timber.

DEATH OF THE TREES.

The physiological changes which take place in the bull pine (*Pinus ponderosa*) as a result of the attack of the pine-bark beetle (*Dendroctonus ponderosæ* Hopk.[a]) are intimately connected with the fungus diseases under consideration, and may therefore be referred to briefly.

According to Hopkins, the beetles enter the bark of the living trees in July, August, and September. The primary longitudinal burrows or galleries are excavated by the adult beetles, and the transverse, broad, or larval mines (Bull. 32, n. s., Division of Entomology, U. S. Department of Agriculture, Pls. I and III and fig. 1) through the inner bark and cambium of the main trunk have the effect of completely girdling the tree, and by September the cambium and the bark on the lower portion of the trunk are dead. The foliage of the trees thus attacked, however, shows no change from the normal healthy green until the following spring, when the leaves begin to fade.

The first signs of disease noticeable in an affected tree are visible in the spring of the year following that of the attack by the beetle. Here

[a] Hopkins, A. D. Insect Enemies of the Pine in the Black Hills Forest Reserve. Bull. 32, n. s., Division of Entomology, U. S. Dept. of Agriculture, pp. 9, 10.

and there one will find the needles of affected trees turning yellowish. The bright green fades almost imperceptibly, starting near the tip of the needle. The needles first affected are those on the lowest branches (Pl. II), and on these branches the discolored leaves will be more or less scattered. By the end of May most of the leaves on an affected tree will be pale green or yellowish. (Pl. II; Pl. III, 2.) This yellow color increases in intensity during the summer and makes the affected trees a conspicuous mark among the healthy green trees. Trees in this stage are locally known as "sorrel tops" or "yellow tops." When standing on a hillside, groups of "sorrel tops" can be easily detected at a distance of several miles. It is rather a difficult matter to show the contrast in a photograph. The middle tree on Pl. II, fig. 1, shows the contrast with the green trees on the left to some extent.

The yellow needles are drier than the green ones and show a marked disintegration of the chlorophyll. As they continue to dry the color changes gradually through various intermediate stages (Pl. III, 3) to a reddish brown. This color (Pl. III, 4) becomes very marked after the trees have passed through the second winter. The needles are then dry and they begin to fall off. Such trees are known as "red tops." (See Pl. II, fig. 1; Pl. IV, fig. 1.) The leaves finally fall off completely, leaving the branches bare. Such trees without any leaves are known as "black tops." (Pl. IV, fig. 2.) The group of trees on Pl. II, fig. 1, shows the green trees and the "sorrel tops" and "red tops" (rapidly becoming "black") side by side.

To summarize the foregoing: One finds the living trees attacked in July and August; the following spring the leaves turn yellow ("sorrel tops") and gradually red ("red tops"), and the third year they drop off altogether ("black tops"). It is a difficult matter to say at what point the trees are dead. Girdled trees die with different degrees of rapidity, depending upon the species. The black gum (*Nyssa sylvatica*) will live—i. e., will have green leaves—for two years after being girdled; so also several species of oak. Pines and spruces rarely live more than a year, and generally not so long.

The reason for the different behavior of these trees is probably to be found in the different power to conduct water through the inner sapwood. The subject is one about which little is known as yet. In the case of the bull pine, after the girdling by the beetles certain changes take place in the cambium and the newer sapwood which leave no doubt as to the death of those parts. By September, as described below, the cambium and bark are actually dead and partially decayed for 30 feet or more from the ground. The leaves are still green and full of water the following spring. The only way in which this can be accounted for is by assuming that sufficient water passes through the inner sapwood to keep the crown of the tree supplied

WHEN ARE THE TREES DEAD?

The question as to when a tree is dead is one of considerable practical importance in determining which trees in the forest should be cut. For this purpose it is safe to assume that a tree may be pronounced dead when the bark is loose at the base of the tree for considerable distances up the trunk. A tree with its bark in this condition can not possibly recover. The wood under this loose bark will always be found to be dark in color and will appear covered with shreds of bark when the bark is pulled off. It must be remembered that such trees will have green leaves. The criterion of green or yellow leaves is not a safe one to follow, and ought not to be considered in making specifications for cutting dead timber. Attention is here called to the recommendation (4) made on page 35.

THE "BLUE" WOOD.

Very soon after the attack of the bark beetles (*Dendroctonus jeffrosæ*) the wood of the pine turns blue. The color at first is very faint, but it soon becomes deeper. A cross section of a trunk several months after the beetle attack will appear much as shown on Pl. V, fig. 1. Lines of color extend in from the bark toward the center of the tree, and increase rapidly in intensity until the colored areas stand in sharp contrast to the unaffected parts. The color appears in small patches at one or more points on the circumference of the wood ring. At first it is a mere speck, but this gradually spreads laterally and inward, eventually forming triangular patches on cross section. The color likewise spreads up and down the trunk from the central spot. As the time passes after the first attack of the beetles, several color patches may fuse. Their progress laterally and upward toward the center of the trunk may be equally rapid on all sides of the tree, or more rapid on one side than on another (Pl. V, fig. 2). The intensity of the color may vary considerably on the two sides of one and the same trunk. After a certain period of time the whole sapwood will have a beautiful light blue-gray color, as shown on Pl. I. The wood which adjoins the inner line of the "blue" wood is of a brilliant yellow color, which contrasts sharply with the blue outside and the straw yellow of the heartwood. This yellow area is in the form of a ring of more or less irregular shape. Sometimes it is formed of one annual ring very sharply defined; then, again, it may include all or only parts of several annual rings. As the wood grows older, the blue color becomes deeper and the yellow ring more sharply defined.

RATE OF GROWTH OF THE BLUE COLOR.

The first signs of the blue color are usually found several weeks after the attack by the beetles at points on the trunk in the immediate

vicinity of the attack. The first signs of the blue color are found in the base of the trunk. On Pl. VI, fig. 1, three sections of a tree which was attacked the latter part of July, 1901, are shown. The sections were cut in November, 1901, at points 5 feet, 16 feet, and 36 feet from the ground. The sapwood of the first section, 5 feet up, is entirely blued; the second section, 16 feet up, is blue here and there; while the section made in the top, 36 feet up, is without a particle of blue color. Note in this connection that the sections with blue color show the cross sections of the galleries of the bark beetles (*Dendroctonus ponderosæ*) in the layer formed by the cambium layer, the outer wood, and the inner bark. The sections on Pl. VI, fig. 1, show some of these galleries filled with sawdust. A more advanced stage is shown on Pl. VI, fig. 2. In this tree the sapwood is blue from the ground up into the extreme top. The smallest section, cut from the tree in the upper part of the crown, is blue with the exception of the innermost rings, i. e., the beginning of the heartwood.

The blue color develops very rapidly when once the tree is attacked. Standing trees attacked by the beetles in July, 1902, showed signs of blue color in three weeks. Three months after the attack the sapwood of the lower part of the trunk is usually entirely blue, as shown on Pl. I. The year following the attack, i. e., when the trees have reached the "sorrel-top" stage, the bluing has reached the top, and late that year, when the "red-top" stage is reached, the entire sapwood is blue (Pl. VI, fig. 2).

An experiment was made during the past summer to see whether the blue color would appear in trees felled before being attacked by the pine-bark beetle. It may be said at this point that they did "blue" just as the standing ones did.

NATURE OF THE "BLUE" WOOD.

Some weeks after the attack by the bark beetles, changes take place in the bark and the newer wood which ultimately result in the bark becoming loose and separating from the tree. When the first flow of resin into the galleries has stopped, the air enters into the galleries, and channels of communication with the outside are established through which the water in the cambium and newer wood can escape. The result of this is that a moist atmosphere prevails in the air chambers, very favorable to the growth of fungi. As the cambium and bark cells lose water they shrivel and break from one another, so that after a few months the bark breaks away from the wood proper. On the south and southwest sides of the trees the bark dies most rapidly, and here, contrary to the general occurrence, it frequently adheres firmly to the tree. On the shaded sides of the trunk the bark becomes loosened, as described, before six months have elapsed. The surface of the wood is moist, very dark in color, and feels somewhat clammy.

Numerous white strands of fungus mycelium make their appearance after six months or more. As the wood of the trunk dries, the bark, loose at first, tightens, so that in the "black-top" stage it adheres quite firmly to the trunk. When cut into, it peels off in large sheets very readily, however.

The "blue" wood differs very little from the sound wood in general appearance, except its color. It is full of moisture at first, but loses this rapidly, so that in two years after the beetle attacks the wood it may be almost perfectly seasoned, even when completely covered with its bark. The "blue" wood is said to be very much tougher than the green wood, so much so that the tie makers in the Black Hills can be induced to cut wholly blued wood only with difficulty. This toughness and a possible reason therefor are discussed hereafter.

STRENGTH OF THE "BLUE" TIMBER.

Ever since its first appearance there has been considerable discussion as to the strength and durability of the "blue" timber when compared with sound timber. It was universally believed that it would prove very much inferior in both respects. A test was made in the testing laboratory of the department of civil engineering of Washington University, St. Louis,[a] to determine the comparative strength of the "blue" and the healthy timber. Sections of tree trunks 5 feet long were cut from trees at points 10 to 15 feet from the ground, and were shipped to St. Louis, where they were sawed into blocks of several sizes. For the compression tests, blocks 2 by 2 by 4 inches and 3 by 3 by 6 inches were cut and planed to the exact dimensions, or as nearly so as possible.

For the cross-breaking strength, sticks 2 by 2 inches by 4 feet, and 3 by 3 inches by 4 feet were prepared. The blocks for these tests were kiln-dried at a temperature of 172° F. until an approximately constant weight was reached. It was found that completely dried blocks would not shear at all. The moisture content of the green blocks was slightly higher than that of the "blue" blocks.

Three kinds of timber were used: A—Green timber; B—"Blue" timber taken from "sorrel-top" trees, i. e., trees dead about one year; C—"Blue" timber taken from "red tops" and "black tops" (mostly the latter), i. e., trees dead about two years.

The tests were made with the machinery described by Johnson in early reports[b] of the Division of Forestry. Every block was carefully measured. The results, reduced to the average crushing strength and the average cross-breaking strength per square inch, are

[a] The machinery was put at the writer's disposal through the courtesy of Prof. J. L. Van Ornum.

[b] Timber Physics, Bulls. Nos. 6 and 8, Division of Forestry, U. S. Department of Agriculture.

given in the following table. The number of pieces used for each test is given in a separate column. It will be noted that the heartwood pieces were kept distinct from the pieces cut from the sapwood.

Compression strength in pounds per square inch.

Kind of timber.	Heartwood.		Sapwood.	
	Number of pieces tested.	Average strength.	Number of pieces tested.	Average strength.
		Pounds.		*Pounds.*
A. Green timber	210	3,919.74	1,575	5,089.98
B. "Blue" timber, 1 year old	190	3,876.44	649	5,130.95
C. "Blue" timber, 2 years old	131	4,017.48	770	5,308.32

Cross-breaking strength in pounds per square inch.

Kind of timber	Heartwood.		Sapwood.	
	Number of pieces tested.	Average strength.	Number of pieces tested.	Average strength.
		Pounds.		*Pounds.*
A. Green timber	338	5,375.26	553	5,832.66
B. "Blue" timber, 1 year old	317	5,361.17	242	5,818.84
C. "Blue" timber, 2 years old	322	5,665	272	6,843.31

The figures given in this table show that the "blue" timber is slightly stronger, both when compressed endwise and when broken crosswise. This result is probably due to the fact that the "blue" wood was slightly drier than the green wood when the tests were made. It is scarcely probable that the presence of fungus threads in the cells of the wood in any way strengthens the fiber. However that may be, these tests show beyond doubt that for all practical purposes the "blue" wood is as strong as the green wood. Under the conditions now existing in the Black Hills Forest, the "blue" wood is certainly very much stronger than the green wood. It is in effect seasoned timber. The trees have stood in the most favorable position possible for drying, with thousands of holes in the bark made by the beetles through which the water could escape, assisted by the winds which constantly sweep by the trunks. Where wood is used, as it unfortunately is in these days, almost immediately after it is cut from the forest, the "blue" wood is certainly as good so far as its strength is concerned as the green wood, and ought not to be discriminated against because of supposed weakness.

LASTING POWER OF THE "BLUE" WOOD.

The wood of the bull pine is one which is not very resistant to decay-producing fungi. Under ordinary conditions, such as are found

in the State of Nebraska outside of the arid belts and in the Black Hills, the wood will last from four to six years when placed in the ground in the form of a cross-tie, for instance. Dead trees may stand in the forest for many years without decaying, especially when killed by fire, but ordinarily when the bark remains on the trees they begin to decay after the third year.

From observations made on the "black-top" trees now standing in the forest it would seem that the lasting power of the "blue" wood would be very small. It is perhaps not fair to compare these trees with sound ones, for their bark is full of holes, giving fungus spores every opportunity to enter, as described below. When placed in the ground this wood rots very fast, if one can draw conclusions from the dead tops lying around in the forest. There is every reason why it should rot rapidly. The hyphæ of the "blue" fungus have opened passageways for the rapid entrance of water and for other fungi in almost every medullary ray. Dried wood will probably last a long while, especially if properly piled, so as to allow the air to circulate between the separate pieces. When sawed and split for cord-wood, the "blue" wood should keep just as long as the green wood. The tendency to rapid decay can be largely done away with by treating the wood with some preservative. Ties were cut during the past spring from green timber and from dead trees. These were shipped to Somerville, Tex., where they were impregnated with zinc chloride. These ties were laid in the tracks of the Santa Fe Railroad and are now under observation. A second lot of ties has been cut during the past summer from green trees and from "sorrel tops," "red tops," and "black tops." These will be treated within a short time and laid in the track of a Mexican railway so as to determine the relative resistance of the various grades of "blue" timber in a tropical climate as compared with the green timber. On the particular road chosen for this experiment the life of very resistant timbers is short.

THE "BLUE" FUNGUS.

The blue color of the wood is due to the growth of a fungus in the wood cells. The staining of wood due to fungi has been known for many years, especially the form known as "green wood" (*bois verdi*). In Europe this green coloration attracted the attention of foresters and investigators as early as the middle of the last century, and a number of descriptions and discussions appeared from time to time (particularly in France), in which an attempt was made to account for this phenomenon. A green dye was extracted from this wood, which at one time was thought to be valuable because of its absolute permanency. Various dicotyledonous woods showed the green color; among others, beech, oak, and horse-chestnut.

In spite of numerous investigations, the causes of the green color and its relation to the wood remained comparatively obscure until recently, when Vuillemin published an extended account[a] showing that one form of the green color was due to the growth in the wood of one of the Discomycetes, *Helotium æruginosum*. Vuillemin mentions a number of other fungi which have been described as causing the green color, among others, *Propolidium atrocyaneum* Rehm, on wood of the poplar; *Nævia æruginosa* Rehm, on the tansy; and *Fusarium æruginosum* Delacroix, on potato tubers.

Without going into details, Vuillemin established the fact that the green coloring matter, called xylindeine, is formed by the hyphæ of *Helotium æruginosum*, and that the presence of these green-colored hyphæ gives the green color to the wood. The wood fiber itself remains colorless. The xylindeine is soluble in alkalis and can readily be extracted. The wood fiber is not destroyed, but remains intact. The name "green decay" is therefore incorrectly applied, for the green wood is in no sense decayed. This is an interesting fact, for it will be remembered that the same has been said of the "blue" wood. A more detailed comparison of the relation of this green coloring matter and the fungus forming it to the coloring matter in the "blue" wood will be published in another paper.

The blue stain of coniferous woods is a familiar defect in the United States, particularly in the South, where freshly sawed lumber, especially shingles and lath, is affected during the moist warm weather of April, May, and June. The blued lumber is considered as a low-grade material, and many precautions are taken by Southern manufacturers to prevent loss. A full account of this trouble and a discussion as to its cause and methods for its prevention are now in preparation.

In Europe the blue color of pine wood was first noted by Hartig,[b] who refers briefly to the fact that a fungus (*Ceratostoma piliferum* (Fr.) Fuckel), is the cause of bluing in coniferous wood, especially of pine trees which have been weakened by caterpillars, and of firewood. He states that the hyphæ of this fungus, which are brown, grow rapidly inward into the trunk through the medullary rays and that they avoid the heartwood, probably because of its small water content.

The blue color of coniferous wood in this country is probably caused by the same fungus referred to by Hartig, although it seems necessary to refer to it under a different name (*Ceratostomella pilifera* (Fr.) Winter).

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[a] Vuillemin, Paul. Le Bois Verdi. (Bull. de la Soc. d. Sciences de Nancy, Ser. II, **15**: 90–145; 1898. 1 pl.) References to earlier works on the green color are given in this paper.

[b] Hartig, Robert. Lehrbuch der Pflanzenkrankheiten, 1900, pp. 75 and 106. (See also earlier editions of the Lehrbuch für Baumkrankheiten; see also Frank, A. B., Krankheiten der Pflanzen, **1**: 107, 1895.)

CERATOSTOMELLA PILIFERA (Fr.) Winter.

Sphæria pilifera Fr. Systema Myc., 2: 472, 1830; Berkeley, Grevillea, 4: 146, 1876.

Sphæria rostrata Schum. Enum. Fl. Sac., 2: 128.

Ceratostoma piliferum (Fr.) Fuckel. Symb. Myc., p. 128; Ellis & Everhart, N. A. Pyrenomycetes, p. 193.

Ceratostomella pilifera (Fr.) Winter. Rabenhorst's Kryptogamenflora, etc., I, Pt. II: 252, 1887; Engler & Prantl, Nat. Pflanzenfam., Pt. I, Abt. 1: 406; fig. 259.

The "blue" fungus was first described by Fries, who placed it in the genus *Sphæria*. Later it was placed in a new genus (*Ceratostoma*) by Fuckel, and remained in this genus until recently, when Winter in his revision of the family *Ceratostomeæ* put the fungus in the genus *Ceratostomella*.[a] This genus is characterized as "peritheeia more or less superficial, or immersed (sometimes only for a short time), generally tough, leathery, or carbonaceous, with marked, generally well-developed beak. Spores variable, typically unicellular, hyaline. Species mostly on wood." The genus *Ceratostoma* differs from *Ceratostomella* only in having the spores brown instead of hyaline. This seems a very weak character upon which to separate two genera, and Winter realizes this, as indicated in a note (p. 253), where he says: "I hesitate to accept the genus *Ceratostomella*, for the different color of the spores does not seem to be sufficient basis for a genus. I do it only to satisfy generally accepted demands."

As the present investigation is not materially concerned in the validity of any particular name, the writer accepts Winter's name, leaving the question of whether it ought to be *Ceratostoma* or *Ceratostomella* to others.

Ceratostomella pilifera occurs, according to Winter, on coniferous woods, mostly on pine timber. Winter remarks that in spite of the very common occurrence of this species, he was able to find the mature asci but once, and gives a figure of the two asci he saw. This is borne out by the findings mentioned hereafter. Four forms of *C. pilifera* are described, which are probably forms modified by the substratum on which they grew, and of less interest in this connection.

The fruiting bodies of the "blue" fungus occur in thousands on blued logs and boards in favorable seasons; the long necks of the peritheeia when looked at sideways form veritable forests on a board. In the pine forests of the Black Hills the peritheeia are to be found on decaying sticks, in the cracks formed when trees or branches break off, and sometimes under the loosened bark of dead trees. It is a strange fact, however, for which no very plausible reason can as yet be assigned, that with the thousands of dead and "blue" trees now in that forest the asci of the fungus should be comparatively so rare.

[a] Saccardo, P. A. Michelia, 1: 370.

The growth and development of the fungus may be briefly noted as follows:[a] The spores of the "blue" fungus (Pl. VII, 8) are probably blown about by the wind in countless thousands, and at the time of the beetle attack in July and August some of these spores lodge in the holes made in the bark of the living pine tree by the bark and wood-boring beetles. The atmosphere of these holes is constantly kept moist by the water evaporating from the trunk. In these holes the spores can germinate within a day after falling there.

In drop cultures of pure water the spores germinate readily over-night. The hyphæ grow into the bark tissues and into the cambium, and from there they enter the cells of the medullary rays. The readiness and rapidity with which the hyphæ grow into the medullary rays lead one to suspect that the food substances, stored in the medullary rays at this period of the year in considerable quantities, exert a chemotropic stimulus. In the early stages of development one finds the hyphæ of the "blue" fungus only in the medullary ray cells. After a hypha has entered one medullary ray cell it branches and spreads to the neighboring cells (Pl. VII, 1 and 2; Pl. VIII, figs. 1 and 2), so that in a very short time the entire ray is filled with the hyphæ, most of which grow in the ray toward the center of the trunk. Numerous starch grains are usually found in the ray cells during the early part of August; these are rapidly dissolved by the fungus and serve as a source of food supply for a considerable period of time. The hyphæ are at first colorless, very thin-walled, and full of vacuoles and oil globules. They branch rapidly, forming numerous septa. If the starch supply is abundant, hyphæ several microns in diameter may be formed (Pl. VII, 2). These are constricted at the septa and show signs of rapid development. The older hyphæ turn brown, and with the first signs of the brown color in the hyphæ the bluish coloration of the wood begins. One of the first effects seen after the hyphæ have entered the medullary ray cells is the gradual solution of the walls separating the medullary ray cells from one another (Pl. VII, 1, 2, and 3). The walls which separate the ray cells from the neighboring wood cells may become very thin, as shown in the middle ray (Pl. VII, 1), but they are rarely dissolved entirely. The intermediate walls, on the other hand, entirely disappear. This leaves a tube with a cross section having the shape of the cross section of the ray, extending into the trunk from the bark. This tube is sometimes filled entirely with a mass of brown hyphæ, the larger number of which extend in the direction of the ray (Pl. VIII, figs. 1 and 2). From the ray cells some hyphæ make their way into adjacent wood cells (Pl. VII, 2; Pl. VIII, figs. 1 and 2). They grow along these, both up and down

[a] A fuller discussion of its cultural characteristics, spore germination, and the blue color will be printed at a later date.

(Pl. VII, 1), giving off branches to other wood cells.[a] In this manner the whole wood body becomes penetrated by the brown hyphæ in a very short time after the first infection. The number of hyphæ in the wood cells proper, i. e., excluding the medullary ray cells and the cells of the wood parenchyma, is very small indeed. This is probably due to the fact that the fungus finds scant material upon which to live in the wood cells. The hyphæ are apparently able to puncture the unlignified walls here and there, but they stop at that point. The writer was not able to demonstrate that the hyphæ could attack the lignified walls. In other words, the "blue" fungus is one which confines its attack to the food substances contained in the storing cells of the trunk and to the slightly lignified walls of these storing cells. The best instance of the resistance which the lignified walls offer to the dissolving action of the hyphæ is found in the outer walls of the medullary rays, which are composed in part of the more heavily incrusted walls of the adjacent wood fiber.

The resin ducts are attacked in much the same manner as the medullary rays. (Pl. VII, 3; Pl. VIII, fig. 2.) The walls of the component cells are dissolved, leaving a tube filled with brown hyphæ. When looked at with a low-power magnifying glass, a cross section of the wood shows the resin ducts as black spots in the wood ring.

The rate at which the hyphæ advance in the medullary rays keeps them considerably in advance of the hyphæ in the wood cells and also of the blue color which follows the appearance of the hyphæ in the rays. When the hyphæ have reached the heartwood they cease growing inward. One reason for this may be the absence of food materials in the rays of the heartwood, and another may be the greater lignification of the heartwood cells. It is very certain that the hyphæ do not flourish in the heartwood, neither in the medullary rays and resin ducts nor in the wood cells proper. Hartig ascribes the restriction of the fungus to the sapwood to the smaller amount of water in the heartwood, but it would seem to the writer that there would hardly be so very sharp a line between the points where growth does take place and where it does not, if it were a matter of water supply alone. The readiness with which the fungus can enter heartwood and sapwood cells and the presence or absence of food substances would seem to be factors of more importance in determining the regions where the fungus could or would not grow.

The growth in the medullary rays comes to a stop within six months after the first infection, and perhaps earlier. This applies to such wood as is infected in July or August. By December or January the whole sapwood will be filled with hyphæ. In the top of the tree the

[a] The hyphæ growing out from the medullary rays, as shown in Pl. VIII, fig. 2, make the wood cells appear septate. This, of course, is not the case.

development is probably very similar, although it was not possible to make an accurate determination of this fact because of the great irregularity in the rate with which infection takes place after the beetle attack. The rate of growth in the trunk varies considerably. Some trunks are invaded on all sides with equal rapidity; some, on the other hand, seem to be more resistant on one side or another. A good idea as to the presence or absence of the fungus can usually be obtained by observing the extent of the blue coloration, to which reference is made below.

EFFECT OF "BLUE" FUNGUS ON THE TOUGHNESS OF THE "BLUE" WOOD.

On page 13 it was stated that the "blue" wood was considered very much tougher than the healthy wood. The tie cutters in the Black Hills find that it is very much harder work to cut cross-ties from the "black-top" wood than from green trees—so much so that they demand additional pay for cutting these ties.

When split with an ax, the two halves of a block seem to hang together more firmly, and it requires more strength to wedge them apart. Chips do not fly off as easily. The only explanation which can be suggested for this peculiar behavior of the diseased wood is that in the "blue" wood we have an enormous number of filaments, all extending radially through the wood. These filaments occur in bunches, much interwoven, scattered at regular intervals through the wood. It is estimated that at a point about 1 foot in from the bark there are about 39,000,000 medullary rays per square meter of tangential surface, or about 3,700,000 per square foot. Even if the tensile strength of one hypha is not very great, when it comes to 4,000,000 bundles these may have some effect in holding masses of wood fiber together (see Plate VIII). This view is strengthened by the fact that it seems easier to split the "blue" wood along radial lines than on tangential lines. In making ties the tangential cut is used almost entirely, and it is possible that these hyphal bundles are responsible for the toughness. When split tangentially and viewed edgewise, one can see some of these hyphal bundles projecting from the medullary rays, as if they had been pulled out and stretched before being torn.

RELATION OF THE "BLUE" FUNGUS INFECTION TO THE BEETLE HOLES.

As has been previously stated, the first evidences of the presence of the "blue" fungus are seen some weeks after the beetles have bored into the cambium layer. The first signs of blue color in the wood might be expected just under a hole in the bark or near such a hole, or under the tube excavated in the bark extending from such a hole. This, however, is not always the case; in fact, is rarely the case. The small triangular patches of color may appear anywhere within the area

attacked by the beetles. Why this should be so it is difficult to explain satisfactorily. The spores must enter the region between the wood and the bark through the beetle holes and burrows, for there is no other way for them to get through the bark. Cracks in the bark are practically entirely wanting in the living trees. The only explanation possible is that the hyphæ start their growth in the bark and cambium layer, the parts richest in food materials, and then grow inward at one or more points independent of the beetle holes.

As soon as the living bark and wood die, a wood-boring beetle enters the wood and makes numerous small holes all through the sapwood (see Pl. IX). It enters felled trees within a few days after the tree is cut. The holes which it makes extend radially into the trunk, sometimes with great directness, then again obliquely. The beetles bore with great rapidity, so that they may have reached the heartwood in the course of a few months. These holes form very convenient channels for the entrance of the hyphæ of the "blue" fungus, and they take advantage of their opportunities. Before they appear in the wood cells surrounding the holes made by the wood-boring beetle, one finds great masses of another fungus in the open ends of the wood cells bordering the hole. This is the so-called "ambrosia" fungus,[a] which the beetles carry into the holes with them, and upon the spores of which they feed. The hyphæ of this fungus are colorless and thick walled. They extend into the wood cells away from the holes only a short distance, but near the holes they grow into dense mats, which practically plug the lumen of the wood fibers toward the beetle hole. The bunches of sporophores with the round pores project into the beetle hole from these mats.

The hyphæ of *Ceratostomella* can be distinguished readily from those of the "ambrosia" fungus. They are thin walled, full of vacuoles, and turn brown very soon. There seems to be no relation between the two, although such a relation is not impossible. The development of the "ambrosia" fungus is now being investigated, and it is hoped that this study will throw more light on any possible relation.

This class of beetle probably carries the spores of *Ceratostomella* with it into the holes it makes, much as it carries the "ambrosia" spores. This seems probable from the fact that the "blue" fungus seems to start at various points along a beetle hole; in other words, it does not grow down into the hole from the outside. Sections made at right angles to the hole show that the fungus starts to grow on all sides of the hole, and that it makes most rapid headway in a direction parallel to the long axes of the wood fibers (Pl. IX). When once the hyphæ have reached the medullary rays from the wood fibers, progress in all directions

[a] Hubbard, H. G. The Ambrosia Beetles of the United States. Bull. 7, n. s., Division of Entomology, U. S. Dept. of Agriculture, 1897, pp. 9–30.

becomes equally rapid. The blue color appears around the beetle holes soon after the entrance of the "blue" fungus. Usually it forms two rings extending from the hole along the wood fibers. Various stages of this first appearance of the color are shown on Pl. IX. The spread of the "blue" fungus within the wood, through the agency of wood-boring beetles, is an occurrence frequently found in many coniferous woods. The central figure at the bottom of Pl. IX is from a photograph of a log of western hemlock found in the Olympic Forest Reserve, in Washington, which shows an even more striking case of the spread of *Ceratostomella* from holes made by *Gnathotrieus occidentalis* Hopkins MS. This particular piece of wood was cut from a fallen trunk, about 6 inches in from the bark.

FRUITING ORGANS OF THE "BLUE" FUNGUS.

The "blue" fungus forms its fruiting bodies on the surface of the wood in which it is growing. Air seems to be necessary for the formation of the fruiting bodies. A good deal of moisture in the surrounding air is necessary likewise. No fruiting organs are formed in dry air. In the forest they occur in the cracks formed when a blued trunk is broken off, on broken branches, and at such other points as are exposed to the air. So far the writer has been unable to find the perithecia of *Ceratostomella* on the surface of standing trunks under the bark, although a diligent search has been made for them at all seasons for two years. When, several months after the beetle attack, the bark becomes loose, so that it separates from the wood, a space is left between the bark and wood. In this space numerous fungi develop in quantities, among others a species of *Alternaria* which lines the pupal chambers of the *Dendroctonus*, and a species of *Verticillium*. The whole atmosphere of this region is surcharged with moisture, and yet the "blue" fungus does not fructify here, for there is probably not enough air.

The black perithecia of the "blue" fungus, *Ceratostomella pilifera* (Fr.) Winter, are familiar objects on blued boards or shingles, where they occur in thousands side by side. The perithecia are formed within a few hours when the conditions are favorable. At various points on the surface of the wood, in some instances out of every medullary ray, masses of hyphæ grow out forming a dense mass which gradually develops into an egg-shaped body (Pl. VII, 4). The surface of the young perithecium shows irregular polygonal markings, which gradually become indistinct as the perithecium turns jet black almost to its tip. At the tip of the young perithecium a number of hyphæ grow out parallel with one another (Pl. VII, 4) in a direction perpendicular to the substratum. They remain colorless at the tip. These hyphæ grow in length with remarkable rapidity and form a long

bristle-like neck several times as long as the diameter of the perithecium (Pl. VII, 6). This neck becomes very brittle as soon as the perithecium is mature, and breaks off at the slightest jar or touch. The tips of the hyphæ composing the neck remain joined at the top until the spores are discharged; they then separate and form a sort of cup-shaped support for the spore mass (Pl. VII, 9). The body of the perithecium when mature is about 180μ in diameter and 160μ high, and is covered with scattering brown hyphæ. The neck averages about 1,050μ in length and 20μ in thickness.

The spores of *Ceratostomella* are elongated and somewhat curved (Pl. VII, 8). They are very small, and the asci in which they are borne are almost round or egg-shaped (Pl. VII, 7) and exceedingly evanescent, so much so that it is very difficult to find them. Hundreds of perithecia in all stages may be examined without showing a sign of asci. When the spores are mature, they are discharged through the neck, either in the form of a large drop (Pl. VII, 5, *s*), or in a long, worm-like mass. The spores are held together by a mucilaginous material, which will not mix with water. It is suggested that this serves admirably to spread the spores through the agency of crawling insects and worms, both common on wood where the perithecia are likely to be found. The spores germinate in water after a few hours, sending out a short hyaline germ tube, which branches very soon after its appearance. The discharge of the spores takes place when a certain amount of moisture has accumulated within the perithecium. A rain storm often brings about a worm-like discharge from ripening perithecia. In cultures a globular discharge takes place, probably because of the more equitable distribution of water. The spores measure 5.5μ by 2.5μ, average.

GROWTH IN ARTIFICIAL MEDIA.[a]

The "blue" fungus grows quite readily in artificial media. In pine agar the mycelium develops rapidly; less so in ordinary agar or gelatin. Cultures are most readily obtainable in pure condition by inoculating pine agar tubes with pieces of blued wood removed (with care so as keep them sterile) from the inner portion of a blued log. The hyphæ grow out from the blued pieces and soon grow through the agar to the surface. On nearly all cultures of this character perithecia developed on the surface of the agar within a week. The ascospores germinate in a few hours, and at the end of thirty-six to forty-eight hours a colorless mycelium bearing large numbers of conidia has developed. At first these conidia were regarded as contaminations, but their repeated appearance in cultures made from pure cultures of the

[a] The cultural work was carried on in conjunction with Mr. George G. Hedgcock, assistant in pathology.

ascospores leaves no doubt as to their being a stage of the "blue" fungus. Cultures made from these conidia developed a mycelium on which both conidia and perithecia appeared. Work with these conidia is still in progress and a report upon the results accomplished is to be published in full at a later date.

In four to five days in good growing cultures on rich pine agar or on sterile pine blocks the older threads of the colorless mycelium begin to turn brown, and at the end of seven to nine days young perithecia begin to form. These are at first hyaline and change rapidly from brown to black. They mature quickly, and at the end of from twelve to eighteen days some will be found ejecting the ascospores. In twenty-one days nearly all perithecia in a culture will be mature.

DISSEMINATION OF THE SPORES.

The sudden appearance of the "blue" fungus on lumber piles and over large areas at once, and its simultaneous appearance within the trunks of the pine trees seem to point to the distribution of the spores of the fungus by the wind. It was thought that the bark beetles might be instrumental in carrying the spores into their holes. This they might do by having the spores adhering to their bodies or by feeding on the spores and depositing these in their holes. To test these hypotheses, beetles were placed in tubes of melted pine agar, thoroughly shaken, and then plated. Quite a number of beetles were dissected and cultures were made, using their alimentary canals, as well as some of their feces, as infecting material. In none of these cultures did any "blue" fungus appear. A very characteristic bacterium was obtained from the alimentary tracts, but no *Ceratostomella*. A number of live beetles (*Dendroctonus*) were allowed to walk about on pine agar plates, but no "blue" fungus developed. These trials are by no means to be regarded as conclusive, for they were not exhaustive. They are to be repeated on a larger scale this winter and in the summer when the beetles emerge. The number of perithecia developing on dead sticks and in cracks is sufficient to account for any infection which takes place in the Black Hills forest. This applies with equal force to all regions where the "blue" fungus occurs.

The months of May, June, July, and August are the ones during which the most rapid development of this fungus takes place.

THE BLUE COLOR.

Wood in which the mycelium of *Helotium æruginosum* (and probably of other "green" fungi) grows turns green very soon after the fungus gets into the wood. As shown by Vuillemin and others, the green color is due to a substance formed as a product of metabolism of the fungus, which is deposited in the form of regular granules in

the hyphæ and fruiting bodies of the fungus. The green matter, xylindeine, is confined to the fungus threads and in no way stains the wood fibers. Vuillemin states expressly (p. 144) that "there is no green decay or green staining of the wood. The wood appears green when the colored thallus of *Helotium æruginosum* or of analogous fungi is found in its elements." With the highest powers of the microscope he was unable to find any coloration of the walls of the wood. The green color is therefore due to the presence en masse of green-colored threads.

Similar instances of color due to the presence of colored mycelium are found on pine and spruce wood, where brown and black lines are formed by masses of dark hyphæ bunched at particular points in the wood cells. The familiar zigzag and fantastic lines often found in wood of the tulip tree and in birch and maple are due to similar fungus threads. In none of these cases are the wood fibers themselves colored.

So far as known to the writer, no attempt has ever been made to explain the nature of the blue color of coniferous woods. The color is a difficult one to define. A number of the writer's artist friends who were called into consultation pronounced it a blue gray, approaching Payne's gray. Freshly cut wood looks decidedly blue, but as the wood dries the color fades somewhat and dry wood is mouse gray. The color is by no means regular; here and there some of the yellow of the healthy wood shines through. The drawing shown on Pl. I is perhaps a little too blue. Pl. V is closer to the real color. Certain portions of the blued wood look greenish when viewed obliquely.

There are two possible explanations as to the cause of the so-called blue color: (1) The wood may appear colored because of the presence of the colored fungus threads in the wood. The mass effect of such colored threads might make the wood appear colored. (2) The wood might be colored by a pigment or stain formed either by the fungus or as a result of the fungus growth in the wood, and this pigment might stain the walls of the wood fibers.

The first explanation holds good for the "green" wood. Here a pigment is formed in the hyphæ and fruiting bodies of the fungus, and it is because of the presence of the green-colored bodies in the fungus threads, according to Vuillemin, that the entire wood looks green. Careful examinations made of the "blue" wood by persons trained to observe colors, called into consultation by the writer, have led to somewhat conflicting results, and it is therefore thought inadvisable in the present stage of the investigation to enter on a lengthy discussion of the color subject. A number of facts may be stated, however. Examinations of the wood fibers of sound and "blue" wood showed that it was possible in most instances to distinguish between the sound and the "blue" wood. The walls of the sound wood look somewhat darker (with a suggestion of purple) than the blued fiber. This method

of examination, with high magnification, is a rather uncertain one, however, for the refraction caused by the containing liquids, which are purplish, and of light falling from a blue sky, is apt to show very faint traces of color which do not belong to the wood. It may be stated definitely that the fibers of the "blue" wood show no indication whatever of any color element seen in the wood en masse.

The hyphæ constitute the only color element present in the "blue" wood which could not be detected in the sound wood. These are present in the medullary rays and adjacent cells, as described above. These hyphæ are pale reddish-brown, a color which may be obtained by taking a pale tinge of warm sepia. This color is very distinct and stands out in sharp contrast to the surrounding yellow wood fibers. (See Pl. VIII, showing the contrast.) How these brown hyphæ could make a blue gray or mouse gray it is difficult to understand, for no density of such a brown, even in combination with straw yellow (of the wood fiber), could possibly produce blue gray. It would therefore seem probable, or at least possible, that there is some pigment with a blue element in the "blue" wood which is so faint that its detection in thin microscopic sections becomes almost impossible.

All efforts to extract any color of a blue nature from the wood have so far failed. Extracts of blued wood with ether, alcohol, benzol, chloroform, alkalis, and acids gave evidence that changes of some sort had taken place in the wood fiber, for the extracts of sound and "blue" wood differed materially in nearly every instance. No signs of any blue or blue-gray color were obtained.

It seems necessary, therefore, to leave this matter for further investigations, which are now in progress.

SUMMARY.

In the foregoing chapters a peculiar disease of the dying wood of the bull pine has been described. The wood turns blue in August and September, after the trees are attacked by the beetles. The blue color starts near the base of the tree and gradually spreads upward until the entire sapwood is blue. The "blue" wood is somewhat tougher than the healthy wood and has been shown to be practically as strong as the healthy wood.

DECAY OF THE "BLUE" WOOD.

The changes which the "blue" fungus brings about in the wood of the western yellow pine can hardly be called decay. It is true that the medullary rays are destroyed in part and that the walls of many wood fibers are punctured, but as a whole the wood is sound in the ordinary acceptance of that term. It is not rotten, or doty, or decayed. The "blue" fungus attacks cell contents and not the cell walls.

After the wood has been dead for some time certain changes begin, which in the end result in the entire decay of the wood. The dead wood may or may not be blue, for the processes by which the wood changes to decayed wood are the same for wood which is entirely healthy and for the "blue" wood.

THE "RED ROT" OF THE WESTERN YELLOW PINE.

The "red rot" of the western yellow pine usually starts in the tops of the "black-top" trees, i. e., trees which have been dead for two or more years. At one or more points, usually on the north or east side of a tree, one will find that the wood immediately under the bark starts to rot. This rot starts at the bark and gradually extends inward (Pl. X, fig. 1). The wood when it shows the first signs of this decay is wet and soggy and rapidly becomes brittle, so that it crumbles into small pieces when rubbed. A plane will no longer make a smooth surface (Pl. X, figs. 1 and 2), for the knife tears out small pieces of the wood fiber. The color of the wood changes from blue to red yellow. When the decay has gone on for some time, bands and sheets of a white felty substance are found filling certain cracks which result because of shrinkage in the wood mass (Pl. X, fig. 2). These white sheets consist of masses of fungus threads densely interwoven. The destruction of the wood continues until the heartwood is reached, and as this is exceedingly small in the tops of these trees one will find that after some time almost the entire wood mass has changed to a brown, brittle, resistless mass (Pl. XI). The completely rotted wood crumbles into a fine powder when crushed between the fingers. When wet it is of a cheesy consistency. When the water has evaporated from such wood it is like so much brown charcoal.

CAUSE OF THE "RED ROT."

The "red rot" of the dead timber is caused by one of the higher fungi which grows in the wood, and by so doing brings about the decay of the wood. The spores of this fungus fly about in the forest and some of them lodge in bark crevices of the dying trees. The numerous beetle holes afford every opportunity for entrance to the wood, and it is therefore not surprising to find that the majority of the "black-top" trees become infected sooner or later with the spores of this fungus. The spores germinate and hyphæ grow into the dead cambium and the wood, where they attack such organic matter as has been left by the "blue" fungus. They go farther, however, and attack the cell walls of the wood fibers, from which they extract the cellulose. As a result of this, the wood fibers shrink in volume and crack in regular lines extending obliquely across the cell walls. As the solution of the

cellulose goes on, large numbers of fibers separate in a body from the adjoining ones, often along the lines of medullary rays, and the spaces so formed are rapidly filled with fungus threads, giving rise to the white sheets already spoken of. (See Pl. X, fig. 2.)

CONDITIONS FAVORING THE DEVELOPMENT OF THE "RED-ROT" FUNGUS.

One of the most important factors which influences the development of the "red-rot" fungus, and one which holds for all fungi, is water. If the trees in the Black Hills were dry, the red rot would make but slight progress. At the time when the attack takes place the trees are full of water, especially the tops, for these have lived longer than the butts of the trees, and water was pumped into them long after the lower parts of the trees were dead. The top, therefore, is the most favorable point for the "red-rot" fungus, and it is there that it is found developing most rapidly. From the top the fungus may grow down, so as to affect the lower part of the trunk, but as this has been drying continuously since the beetle attack one will find that it is very rare for those parts of the trunk situated at points 5 to 30 feet from the ground to be seriously injured by this fungus in the first years after the death of the trees. This is an exceedingly important consideration when the practical phase of this subject is taken into account.

The relation of the water supply to the "red rot" is illustrated very well in the large number of trees where the bark has died and peeled off from one side of the tree. On Pl. X, fig. 2, a photograph of such a case is reproduced. The bark has fallen off on the south and southwest sides of the tree, but it still is attached to the opposite side. The result of this peeling becomes evident very soon, for on that side the wood dried very rapidly, while on the other side the bark prevented such evaporation. The wood remained moist, and here the "red-rot" fungus found a footing and conditions favorable for its growth. The result was that in the course of some months the north and northeast sides of that trunk were completely decayed, while the opposite side remained sound. A similar instance is shown in the largest section on Pl. VI, fig. 2; in this case at the base of the tree.

Where the bull pine grows on hillsides not exposed to the sun or wind, or where there is much undergrowth, one will frequently find the "red-rot" fungus entering the trees at the base before it attacks the top. This is likewise due to the fact that the water has not left the trunk with sufficient rapidity to prevent the attack.

FINAL STAGES AND FRUITING ORGANS.

When the tops become rotted almost to the heart they become so weak that they are broken off by the first wind. In those sections of

the Black Hills Forest Reserve where the beetle attack took place some four or more years ago there are thousands of dead trees standing with their tops broken off much like those shown in Pl. XII. In this view the tops can be seen lying on the ground. Pl. XIII, fig. 1, shows the lower end of one of these tops. One will note how sharp it has broken off—almost straight across. One of the sheets of mycelium has curled over at the extreme right of the figure. The cross sections of such a top (reproduced on Pl. XI, figs. 1 and 2) show how completely the wood has been destroyed and that there is small chance for such a top remaining on the tree very long.

Where the "red-rot" fungus attacks the tree at its base it brings about the decay of the larger roots underground, and also of the sapwood of the trunk close to the ground (Pl. VI, fig. 2, large section, and Pl. XI, fig. 3). After a time the roots become weakened to such an extent that they are no longer able to keep the trunk in an upright position, and the result is that the tree is blown over. Such a fallen tree is then attacked rapidly at all points by the "red-rot" fungus, and in a few years nothing is left of it but a pile of rotted wood.

When the wood has been completely destroyed the fruiting organs of the "red-rot" fungus begin to form. Some of the hyphæ grow out through the bark and form a flesh-colored knob (Pl. XI, fig. 1), which rapidly increases in size and turns reddish in color. This knob gradually widens horizontally, forming a shelf, and on the lower side of this shelf numerous pores appear. One of these bodies is seen growing out from the fallen top shown on Pl. XIII, fig. 1, a little below and to the right of the small branch extending out toward the front of the picture. (See also Pl. XI, fig. 2, and Pl. XIII, fig. 2.) After a year a mature fruiting body or sporophore (commonly called a punk, mushroom, or toadstool) has developed, from which spores are discharged at intervals. These spores are formed in the small tubes found on the lower side of the sporophore, and on a quiet night one can see them coming from the sporophore in white clouds as they are being discharged in countless thousands. The spores are so light that they are carried many miles by the winds and lodge on every stick and tree in the vicinity.

The sporophores of this fungus may grow for many years. At different periods, the length of which is not yet definitely known, they add a ring on the outside and thereby increase in size. The one shown attached to the section on Pl. XI, fig. 2, is probably 2 years old, while the one at the base of the tree on Pl. XIII is probably several years old. The sporophores may occur singly or in groups of two or three together. When a top falls so as to lie close to the ground where it is likely to be kept wet, the sporophores will develop every few inches, so that there may be as many as 20 or 30 on a log 10 feet in length. On

standing trees they occur only at the base of the trees (Pl. XIII). Here they grow close to the ground and oftentimes their lower surfaces are actually in the ground. Grass, pine needles, and stones almost hide the entire sporophore.

Older punks are rough on top and appear to be covered with some waxy substance which has hardened and cracked. This substance, when scraped, resembles a hard resin. It is brittle, and is readily soluble in alcohol and xylol. It has a sticky appearance, and when freshly formed on the younger parts its bright red color forms a distinguishing character not readily overlooked. The younger parts are sometimes flesh color, then again reddish yellow in color, and as they grow older they turn more decidedly red. The surface is at first smooth and waxy, and as the sporophore grows older it becomes very much wrinkled. The outer waxy covering cracks (Pl. XIII, fig. 2), and the whole surface then seems to be coated with a dull gray, lime-like substance, which is exceedingly characteristic.

The red-rot fungus belongs to the Hymenomycetes, genus *Polyporus* (*Fomes*), and differs decidedly from other species of this genus. The species most closely related to it are *Polyporus pinicola* and *Polyporus marginatus*. Its whole appearance, its color, hard resinous covering, and very rough surface distinguish it from these species. It has been decided to consider it as a new species—*Polyporus ponderosus*, n. sp.—which may be described as follows:

A large *Polyporus* of the *Fomes* type usually growing singly (Pl. XI, fig. 2), sometimes two or three together (Pl. XIII, fig. 2), broadly applanate; about as thick in the back as it is wide (Pl. VII, figs. 10 and 11); top, when young, flesh-colored to yellow red, becoming darker red with age; smooth when young, rapidly becoming rough and covered with irregular nodules. Older specimens show numerous ridges, formed by regular additions (annual) on the edge and below. Top covered after the first year with a hard, brittle, dull, resinous substance, which cracks as it grows old, and looks sandy or crystalline. Lower surface smooth, pores very regular, almost round, extending out to a line which is about one-fourth inch in width. (See Pl. VII, figs. 10 and 11.) Common on dead trees and fallen logs of the western yellow or bull pine (*Pinus ponderosa*) in South Dakota.

RATE OF GROWTH OF "RED ROT."

The question as to the rate of growth of the "red rot" is one of great practical significance. The "red rot" fungus is the principal cause which prevents the dead wood from lasting indefinitely. It usually attacks the trees when they have reached the "black-top" stage; i. e., toward the end of the second year after the beetle attack, and thereafter. The larger number of trees are probably free from this rot until the third year. To make this clearer, one may make a schedule of the stages through which the trees go, about as follows:

1899, July.—Live trees attacked by the bark-boring beetles.

1899, September.—Wood of the lower part of the trunk starting to blue.

1899, December.—Wood blue to the heart below, and wood of the top partially blue.

1900, May.—"Sorrel-top" stage; leaves turning yellow; wood wholly blued.

1900, October.—"Red-top" stage; leaves red and lower ones starting to fall off; wood blue, but sound.

1901, May.—"Black-top" stage; leaves falling off and fallen wood starting to decay; "red rot" in the tops.

1901, October.—"Black-top" stage; leaves all fallen; top badly decayed and in many instances broken off.

This calendar must be considered a tentative one, based upon observations of two years, although in the main it is probably correct. The "red-rot" part is extremely variable, and can not be assigned to any definite period. The time when the tops will begin to decay is dependent upon the weather at any particular season, the amount of rain, the vigor of the tree and the length of time it takes the tree to die completely after the beetles have attacked it, the position of the tree in the forest, the prevailing winds, and probably other factors more or less related to those mentioned.

It is exceedingly important that this variability be recognized, for its bearing on the cutting and utilization of the dead timber is of the greatest importance. There may be "black-top" trees which will be sound from the ground to the very top, and these trees may have stood in the forest for years in this condition. Not far away one will find others which have barely reached the "black-top" stage which may show signs of decay to within a few feet of the ground. It is therefore entirely impossible to lay down a hard and fast rule, and to state that the "black tops" after a year are all of no value as timber.

The average conditions in the Black Hills are certainly very favorable for the development of "red rot," and one will probably not be very far from the truth when he assumes that after the trees have reached the "black-top" stage they are liable to decay and deteriorate within a comparatively short time; that time probably will not exceed two years.

AMOUNT OF DISEASED TIMBER.

In the foregoing, but brief reference has been made to the actual condition of the forests in South Dakota at this time and to the extent of the injury following the attack of the bark beetles. The amount of dead wood, both standing and fallen, is very large, and as the beetles are still at work, it is steadily increasing. It is, of course, rather difficult to make estimates of the exact amount without an actual survey of the whole region. A trip through the worst region—i. e., north of Spearfish River and west of the Burlington Railroad tracks—was made during the past summer, in company with several expert timbermen.

for the purpose of determining about how much dead and dying timber one could safely count on removing this winter. Estimates were individual, and these estimates[a] agreed fairly well as to the relative amounts of the various grades of timber present. Taking these estimates as a basis, it appears that about half of the timber in this particular region is now dead. This refers to the standing timber, and leaves the fallen timber entirely out of consideration. This immense amount of timber is drying out rapidly and forms a tremendous fire danger. Should fire start in these woods, it would sweep the dead as well as the living trees from the hillsides. The great danger of leaving the trees with the beetles in them, which will be "sorrel tops" next summer, has been pointed out by Hopkins. Besides these two dangers, there is still another point worthy of attention, and that is the loss, under present conditions, of the value of this wood. The following considerations are made, keeping in mind both the protection of the living timber against further insect and fire loss and the possible utilization of the vast amount of dead timber.

POSSIBLE DISPOSAL OF THE DEAD WOOD.

IN THE BLACK HILLS.

Timber from the Black Hills Forest Reserve is now being used by the mining interests in the Hills, and to a very small extent by the railroads on their lines in South Dakota. The mining interests use the wood for mine props, lagging, and fuel. They are absolutely dependent on the timber in the Reserve for the lumber necessary for use in mining, for their fuel, and for their water, which is conserved because of the forests on the hillsides. The railroads use the wood for crossties on the lines which extend from Lead City and Deadwood south to the State line. The timber used for mine props, lagging, etc., by all the mines in the Black Hills is stated to be about 75,000,000 feet at the maximum. The amount of timber used for ties is practically inappreciable, and at this writing most of the tie cutting has practically stopped.

It appears from this that the amount of dead timber which could possibly be used in the Black Hills is not more than 75,000,000 feet.

[a] The exact estimates were as follows:

Kind of timber.	I.	II.	III.
	Per cent.	*Per cent.*	*Per cent.*
Green timber	40	50	50
"Sorrel tops"	25	25	25
"Red tops"	20	15	15
"Black tops"	15	20	10

The third estimate was made by Dr. Hopkins and the writer.

IN THE REMAINING PARTS OF SOUTH DAKOTA.

The Black Hills are situated in the extreme southwest corner of South Dakota, and the only railroad connection which they have with the surrounding territory is southward into Nebraska. It is therefore entirely impracticable to consider a possible use of any of the dead timber in parts of South Dakota outside of the Black Hills.

It appears from the foregoing that only a very small amount of the dead timber can be used in the Black Hills, and that practically none can be taken to other parts of South Dakota. The only practicable method of disposing of this surplus amount would be to ship it out of the State, but this is not permissible under the present forest-reserve law, as will be pointed out hereafter.

VALUE OF THE DEAD WOOD.

The dead wood which ought to be removed from the Black Hills Forest Reserve is of all grades and values, and for practical purposes it is impossible to draw any lines grading the same which will hold good. It must be taken for granted that the only wood which can be considered as worth anything at all is wood which shows no sign of decay or rot. Most of the timber, in fact nearly all, will be blue. The blue color, as has been previously shown, ought not to make much difference as regards its strength, and if properly treated with preservatives it is probable that the "blue" wood will be serviceable for ties and lagging.

The wood which is dead in the forest now rots rapidly, as has been pointed out, and every day that it is left makes large amounts of it less valuable than it was before. At best one may expect that timber which is killed by the beetles one year will begin to decay after two years.

In fixing the price of this dead timber it should be remembered that in order to get it out, lines of railroad would have to be constructed at a very considerable cost. Even with such lines the cost of bringing the dead timber from the forest to points where it could be utilized would be great. The expense of bringing timber from Montana and Wyoming to Nebraska (such cost including the first cost of the timber plus the transportation) will about equal the cost of bringing the timber from the Black Hills to Nebraska. That the wood must have some value to be worth going for at all is obvious, but, as has been pointed out, its value will depend upon the rapidity with which it is removed.

INSPECTION.

One of the greatest difficulties which will be encountered in the utilization of the dead timber will be in connection with the inspection of the material used. There will be vast quantities of the timber

which will be hard and sound, but badly blued. Then again, if the recommendations as to the cutting of live trees which are infested with beetles are followed there will be timber which will in all respects be like the green timber. A tie cut from the top of a tree in September, after the beetle attack in August, will usually be perfectly healthy, i. e., it will show no traces of blue color or only very slight ones.

All timber which is entirely sound, i, e., not decayed, is fit for the uses to which it can be put in the Northwest, either for mine timbers, lagging, ties, etc. The blue color is not to be considered as a sign of decay. Timber which shows rotten spots of any size in the sapwood should not be used. An idea of what such decayed spots look like can be gained by studying the photographs reproduced on Pl. X, figs. 1 to 3, and Pl. XIV, fig. 1. Besides the defect caused by the "red rot," one will sometimes find logs which show decay in the center. This is a disease of the *living* tree, and when more than one or two rings are affected by the disease, such logs should likewise be rejected. The tie section shown on Pl. XIV, fig. 2, is an example of this form of rot.

A careful and intelligent inspector who familiarizes himself with the causes of the decay in the Black Hills Forest Reserve ought to have no difficulty in determining after some practice which timber is fit for use and which ought to be rejected. No amount of chemical treatment will, so far as we now know, make a practically decayed log serviceable.

RECOMMENDATIONS.

Bearing in mind the considerations just referred to, the following recommendations are made:

(1) *Removal of wood from the forest.*—The dead timber should be removed from the Black Hills Forest Reserve at once. It forms a standing fire menace. The standing beetle-infested trees serve to spread the insect trouble. This dead timber should be removed at once, or at the earliest possible moment, and the living infested trees should be felled and peeled as recommended by Dr. Hopkins, for with every day the situation becomes more and more difficult to handle.

(2) *Sale of wood.*—In order to rid the forest of danger from fire, from further insect and fungus spread—in other words, in order to protect the remaining living trees from further destruction—the dead wood should be removed. The cost of operation in removing the dead timber is very considerable: (1) Because of the distance from lines of transportation; (2) because of the greater difficulty in cutting this wood; (3) because of the scattered localities in which it is found; (4) because of the constant care and selection necessary to get good sound wood. Therefore, because of this increased cost, it is recommended that the dead and beetle-infested timber be sold at a nominal

price to such as may apply therefor, this to be done in order to induce persons to assist in clearing the forest with all possible speed.

(3) *Removal from South Dakota.*—It has been pointed out that the great mass of dead timber now in the Black Hills Forest Reserve can not be used in South Dakota. It is therefore recommended (again as a measure of protection for the living forest) that the forest-reserve law be so amended as to permit the shipment of the dead and beetle-infested timber from the State of South Dakota.

In making such a change, it ought to be understood that shipping timber from the State should in no way interfere with the industries dependent upon such timber in the State where the timber is situated. The case under consideration is an example in point. The mining interests of the Black Hills are absolutely dependent for their timber supply on the wood in the Black Hills, and if any timber is removed from the region of the Black Hills, i. e., from the State of South Dakota, it should be taken from regions in the Black Hills which are no tributary to the important mining interests in the Hills. In other words, if any timber is removed from the Black Hills, it should come from the region south and west of the Little Spearfish River.

(4) *Timber which should be removed.*—The timber which should be removed is the dead and beetle-infested timber. For the purposes of inspection dead timber should be considered as timber which comes from trees whose leaves are no longer green—that is, the "sorrel tops," the "red tops," and the "black tops." "Beetle-infested timber" has been specified by Dr. Hopkins.

This dead timber will be "blue timber," and much of it is now decayed. Contractors should be required to cut and remove only such timber as is perfectly sound, without any signs of decay.

PLATES.

DESCRIPTION OF PLATES.

PLATE I.—Frontispiece. Cross section of the trunk of a dying tree of the western yellow or bull pine (*Pinus ponderosa*) from the Black Hills, South Dakota. This tree was attacked by the beetles in August, 1901. The section was cut at a point 6 feet from the ground during the early part of November, 1901. Note the beetle holes in the bark; also the yellow ring between heartwood and sapwood.

PLATE II.—Dying trees of the bull pine. Fig. 1 shows several trees; at the left two live, green trees, a "sorrel-top" tree in the center, and a "red-top" tree at the right. Photographed August 5, 1902. Fig. 2 shows several live, green trees at the left and a "sorrel-top" tree toward the right. Note that this tree is still green at the top. Photographed August 5, 1902.

PLATE III.—Various stages showing the gradual color change of leaves of the bull pine (*Pinus ponderosa*) after they have been attacked by the bark beetles (*Dendroctonus ponderosæ*). 1. Leaves from a healthy tree. 2. Leaves from a "sorrel-top" tree. 3 and 4. Leaves from trees changing to the "red-top" stage. When the leaves have reached the stage of 4 they fall off and are completely dead.

PLATE IV.—Fig. 1. Group of bull pines (*Pinus ponderosa*) near Elmore, S. Dak., showing a "red-top" tree in the center and healthy trees on both sides. Fig. 2 shows a group of "black-top" trees from which all leaves have fallen. This photograph was made in November, 1901, and it is probable that these trees were attacked by the beetles in August, 1899.

PLATE V.—Sections of trunks of the bull pine (*Pinus ponderosa*), showing the "blue" disease. Fig. 1 shows an early stage. This section was cut in November, 45 feet up in the trunk, from a tree attacked by the beetles in August of the same year. The tree is still alive at this point. The blue color has started at two separate points. Fig. 2. A later stage, showing the blue color spread out over one-half of the section. Note the yellow ring at the border of heartwood and sapwood.

PLATE VI.—Fig. 1. Three sections from a bull pine made in November, 1901. This tree was probably attacked by the beetles the latter part of July, 1901. The sections were made at points 5 feet, 16 feet, and 36 feet, respectively, from the ground, i. e., the largest section was cut from the butt, the second one about half way up, and the third in the top. The healthy wood photographs white, and all darker shades represent blued wood. Note the beetle holes in the bark. Fig. 2. Three sections from a bull pine made in November, 1901. This tree was probably attacked by the beetles in July, 1900. It is a "black-top" tree. The sections were made at points 4 feet, 26 feet, and 40 feet from the ground. All are blue. The section near the ground shows "red rot." This happens frequently where the bases of the trees are shaded by long grasses and bushes. In most trees the base will be found sound. The whole tree was dead.

PLATE VII.—Mycelium and fruiting bodies of the "blue" and "red-rot" fungi. 1. Tangential section of "blue" wood; *m*, cross sections of hyphæ of the blue fungus (*Ceratostomella pilifera* (Fr.) Winter), growing in the medullary rays; *h*, hyphæ growing longitudinally in the wood fibers. These hyphæ are brown. 2. Cross section of "blue" wood, showing longitudinal section of medullary ray with hyphæ of the "blue" fungus (*h*) growing in the ray and into adjoining cells; the

ray cells have been destroyed; *m*, cross sections of hyphæ of *Ceratostomella pilifera*. 3. Cross section of a medullary ray, with resin duct showing the internal cell walls wholly dissolved out. Masses of brown hyphæ, *m*, of the "blue" fungus extend longitudinally through the ray. 4. Young perithecium of the "blue" fungus (*Ceratostomella pilifera* (Fr.) Winter), grown on pine agar culture. 5. Mature perithecia of the "blue" fungus (*Ceratostomella pilifera* (Fr.) Winter), grown on pine agar culture, showing the spores, *s*, discharging from the top of the beak. The line at the side equals 0.1 mm. 6. Two perithecia of the "blue" fungus (*Ceratostomella pilifera* (Fr.) Winter) just before the discharge of the spores. Perithecia from culture on pine wood. 7. Two asci with spores of the "blue" fungus (*Ceratostomella pilifera* (Fr.) Winter). 8. Spores of the "blue" fungus (*Ceratostomella pilifera* (Fr.) Winter). 9. Top of beak of perithecium of *Ceratostomella pilifera* (Fr.) Winter, just after the discharge of the spore mass. The hyphæ composing the tip of the beak have spread out, forming a sort of support for the spore mass. 10 and 11. Median sections of sporophores of the "red-rot" fungus (*Polyporus ponderosus*, n. sp.), natural size.

PLATE VIII.—Photomicrographs showing the structure of "blue" wood. Fig. 1. A radial section, showing how the hyphæ of the "blue" fungus grow in the medullary rays, being confined almost entirely to the rays. Magnification, 80 diameters. Fig. 2. A tangential section, showing how the hyphæ completely fill the medullary rays. Numerous small hyphæ grow out into adjoining cells in a tangential direction. This makes the wood cells in the photograph look as if they were septate. The apparent septa are hyphæ. Magnification, 80 diameters.

PLATE IX.—A number of pieces of wood from the bull pine (*Pinus ponderosa*), showing holes made by wood-boring beetles. The trees from which these pieces were taken were in most cases dead, either standing or felled. The "blue" fungus has started to grow in the wood cells bordering on these holes, and is gradually spreading to other cells from these holes as a center. Note that these wood pieces show both radial and tangential surfaces. The piece of wood in the center at the bottom of the plate is western hemlock.

PLATE X.—Sections of "black-top" trees of the bull pine (*Pinus ponderosa*), showing early stages of the "red rot" caused by *Polyporus ponderosus*, n. sp. Fig. 1. Section of a dead tree 35 feet up from the ground. This tree had probably been dead for eighteen months to two years. The decay has just started in at several points on the north and northwest sides of the tree. Note that the larger part of the wood is blue. The healthy, unaffected wood is white. Note also the beetle holes in the bark. Fig. 2. A section from a similar "black-top" tree, showing a more advanced stage of decay. The whole section was blue. The decay started on the side where the bark prevented the rapid evaporation of moisture from the wood and had reached the heartwood. Note the radial and tangential sheets of white mycelium. Fig. 3. A section from the same tree from which fig. 2 was taken, made some 15 feet higher up. The section is blue, but shows few signs of decay. This shows how the "red rot" usually attacks the tree somewhere below the crown.

PLATE XI.—Sections of "black-top" trees of the bull pine, showing advanced stages of decay caused by *Polyporus ponderosus* n. sp. Figs. 1 and 2. These two sections were cut from a fallen top of a "black top" such as is shown in Pl. XIV, fig. 1, one near the point where the top broke off, the smaller one near the top of the crown. Both show how completely the wood has been destroyed. This stage was probably reached about three years after the beetle attack. Fig. 3. The lower figure shows a section cut 4 feet from the ground from a standing "black-top" pine. On one side a fruiting body of *Polyporus ponderosus* is to be seen.

which is probably two years old. The sapwood is wholly converted into a brown, brittle mass. Such a tree is liable to be blown over at any time.

PLATE XII.—A group of "black-top" trees of the bull pine near Elmore, S. Dak., showing how the tops break off after the trees have been dead for some time. Many of the tops are visible, lying near the base of the trees. A single "black top" from which the top has not fallen is seen at the left. The standing trunks are decayed for several feet downward from the point where the top broke off. The base of these trunks is generally sound, and contains enough timber to make a good cross-tie.

PLATE XIII.—Fig. 1. View of a broken top, showing how it has broken off almost straight across. Near the middle of the figure a fruiting body of the "red-rot" fungus (*Polyporus ponderosus*, n. sp.) is growing out. Fig. 2. Base of a dead bull pine (*Pinus ponderosa*) near Elmore, S. Dak., showing a number of fruiting organs of the "red-rot" fungus (*Polyporus ponderosus*, n. sp.) growing out from the wood. These are the bodies variously known as "punks," "toadstools," "mushrooms," or "frogstools." The double one to the left is very old. Note the cracked upper surface. A section of the trunk made at the point where these bodies are growing out would appear much like Pl. XI, fig. 3.

PLATE XIV.—Sections of the ends of two cross-ties cut from dead timber, showing defects which are so serious that ties of this kind should be rejected. Fig. 1. Defective because of the "red rot." Fig. 2. Defective because of a disease of the living timber.

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FIG. 1.—"GREEN," "SORREL-TOP," AND "RED-TOP" TREES.

FIG. 2.—"GREEN" AND "SORREL-TOP" TREES.

DYING TREES OF THE BULL PINE.

COLOR CHANGES IN LEAVES OF THE BULL PINE

1. Leaves from healthy tree. 2. Leaves from "Scorch-top" tree.
3 and 4. Leaves from trees turning of the "Red-top" stage.

Bul. 36, Bureau of Plant Industry, U. S. Dept. of Agriculture.

FIG. 1.—"RED-TOP" TREE IN A GROUP OF HEALTHY TREES NEAR ELMORE, S. DAK.

FIG. 2.—"BLACK-TOP" TREES.

Fig. I

Fig. II

SECTIONS OF TRUNKS OF THE BULL PINE, SHOWING EARLY STAGES OF BLUE DISEAS

FIG. 1.—SECTIONS FROM TREE DEAD FIVE MONTHS.

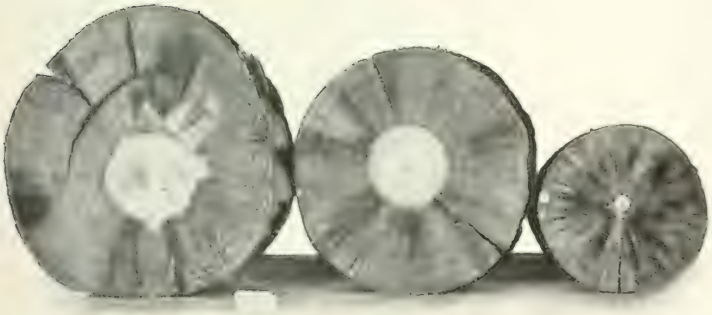
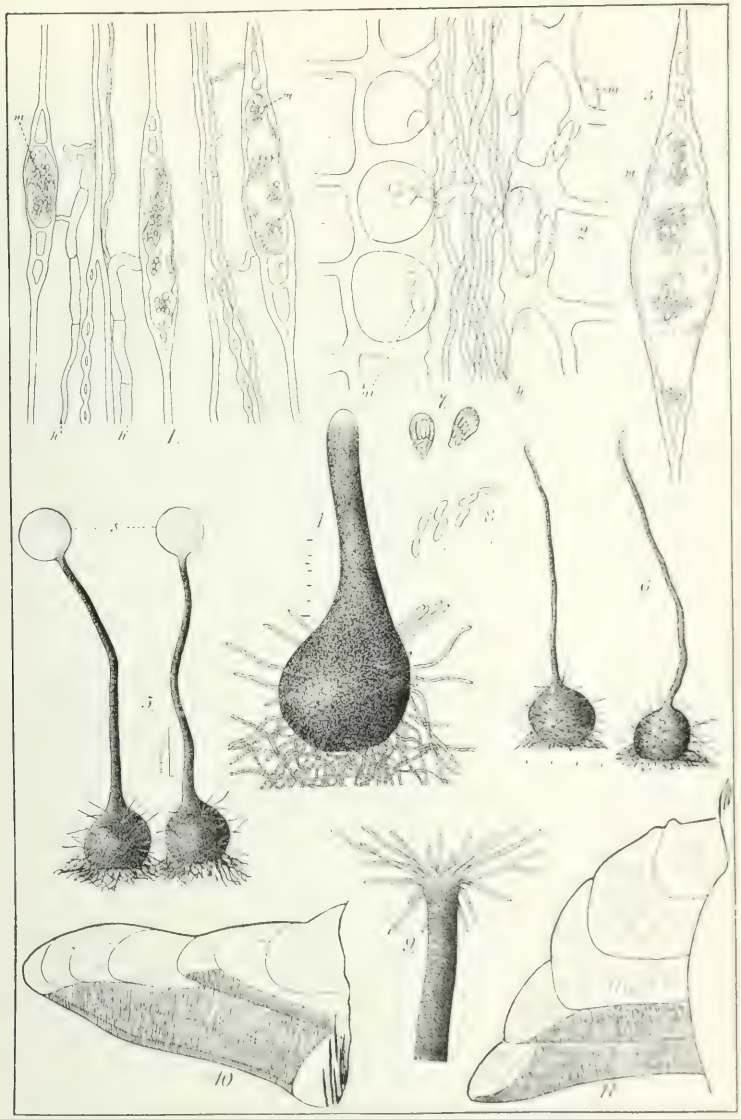


FIG. 2.—SECTIONS FROM TREE DEAD EIGHTEEN MONTHS.

"BLUE" SECTIONS FROM DEAD TREES.



MYCELIUM AND FRUITING BODIES OF "BLUE" AND "RED-ROT" FUNGI.

1, Tangential section of "blue" wood; 2, cross section of "blue" wood; 3, cross section of [illegible]; 4, young perithecium of the "blue" fungus (*Ceratostomella pilifera*); 5, mature perithecium of the "blue" fungus; 6, two perithecia of the "blue" fungus; 7, two asci with spores of the "blue" fungus; 8, spores of the "blue" fungus; 9, top of beak of perithecium of *Ceratostomella pilifera* just after the spore mass; 10 and 11, median sections of sporophores of the "red-rot" fungus *Polyporus*, n. sp.).

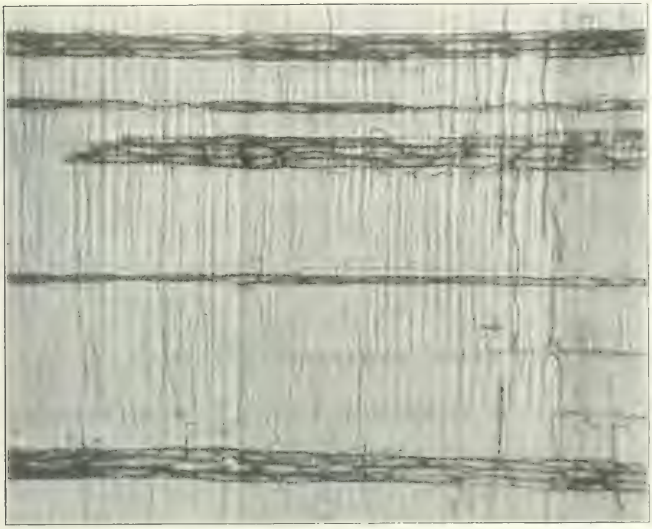


FIG. 1.—RADIAL SECTION.

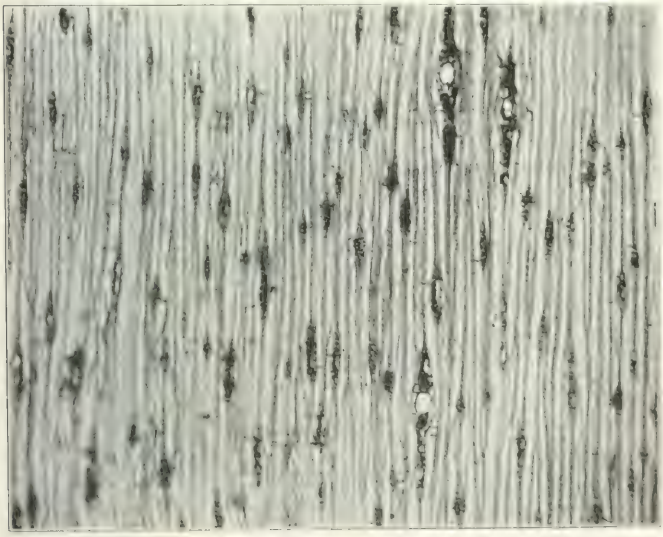


FIG. 2. TANGENTIAL SECTION.

SECTIONS OF "BLUE" WOOD.

PIECES OF WOOD FROM THE BULL PINE, SHOWING BLUE FUNGUS STAINING AND HOLES MADE BY A WOOD-BORING BEETLE

FIG. 1.—SECTION TAKEN 35 FEET FROM THE GROUND FROM A DEAD TREE.

FIG. 2.—SECTION SHOWING MORE ADVANCED STAGE OF DECAY.

FIG. 3.—SECTION FROM TREE SHOWN IN FIG. 2, MADE 15 FEET HIGHER UP.

EARLY STAGES OF "RED ROT."

FIGS. 1, 2.—SECTIONS FROM THE TOP OF A FALLEN TREE.

FIG. 3.—SECTION FROM A STANDING PINE, 4 FEET FROM THE GROUND.

SECTIONS FROM "BLACK-TOP" WESTERN YELLOW PINE TREES, SHOWING ADVANCED STAGES OF DECAY.

GROUP OF BROKEN "BLACK-TOP" TREES

FIG. 1.—TOP OF "BLACK TOP" BROKEN OFF

FIG. 2.—POLYPORUS PONDEROSUS GROWING ON DEAD PINE STUMP

FIG. 1.—WOOD AFFECTED WITH "RED ROT."

FIG. 2.—DISEASED WOOD FROM LIVING TREE.

SECTIONS OF REJECTED CROSS-TIES.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN No. 37.

B. T. GALLOWAY, *Chief of Bureau.*

FORMATION OF THE SPORES IN THE SPORANGIA OF RHIZOPUS NIGRICANS AND OF PHYCOMYCES NITENS.

BY

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ASSISTANT IN PATHOLOGY, LABORATORY OF PLANT PATHOLOGY.

VEGETABLE PHYSIOLOGICAL AND PATHOLOGICAL INVESTIGATIONS.

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BUREAU OF PLANT INDUSTRY.

B. T. Galloway, *Chief.*

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., February 20, 1903.

Sir: I have the honor to transmit herewith a technical paper entitled "Formation of the Spores in the Sporangia of *Rhizopus Nigricans* and of *Phycomyces Nitens*," and respectfully recommend that it be published as Bulletin No. 37 of the series of this Bureau. This paper was prepared by Mr. Deane B. Swingle, of the Pathological Laboratory of Vegetable Pathological and Physiological Investigations, and was submitted with a view to publication by the Pathologist and Physiologist.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The following paper by Mr. Deane B. Swingle, entitled "Formation of the Spores in the Sporangia of *Rhizopus Nigricans* and of *Phycomyces Nitens*," throws a new light on certain intricate processes in two important genera of fungi. The question of spore formation is one of vital interest to the study of the reproduction and distribution of fungi, both parasitic and nonparasitic. Mr. Swingle's paper corrects an erroneous idea that has received wide acceptance both in this country and abroad. The inherent properties and behavior of protoplasm must be the basis of work in pathology and physiology. This paper is a contribution to our knowledge, especially in regard to the mechanics of this type of cell-division, and to the nature and functions of the vacuole and the relation of the activities of the nucleus to those of the rest of the protoplasm. The results of this study are in a large measure applicable to many of the other fungi, including a number that are parasitic.

The paper is technical and is intended for the use of investigators in pathology and physiology.

ALBERT F. WOODS,
Pathologist and Physiologist.

OFFICE OF THE PATHOLOGIST AND PHYSIOLOGIST,
Washington, D. C., February 7, 1903.

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FORMATION OF THE SPORES IN THE SPORANGIA OF RHIZOPUS NIGRICANS AND OF PHYCOMYCES NITENS.

HISTORICAL.

Although the life history and gross anatomy of nearly all the species of the Mucorineæ have been carefully worked over and described, yet in regard to the cytological details there are the widest differences of opinion, chiefly owing to the fact that only a few forms have been studied with the aid of the most recent methods. It seems desirable, therefore, that others should be critically examined. The present paper is a contribution toward that end.

The earliest account that deals specifically with the formation of the spores in the Mucorineæ is that of Corda (1838). He investigated the development of the sporangia of *Rhizopus nigricans*, but was able to discover little of the real nature of the process. After the formation of the columella in the lower part of the sporangium, he describes the spores as being formed in rows radiating from the columella, but just how they originate he does not make clear.

Van Tieghem (1873, 1875, 1876) in a series of classic papers has covered practically the entire group, describing the structure and development of a very large number of forms with much accuracy and minuteness of detail. He believed that the method of spore formation was the same in all the genera having a spherical sporangium. In these forms the sporogenous protoplasm separates itself into two very different substances—the sporal protoplasm which is always granular, and the intersporal protoplasm which is homogeneous and brilliant. The sporal protoplasm has the form of small polyhedric portions, and these are separated from each other by the intersporal protoplasm. Soon the polyhedric masses round themselves off, secrete a cellulose wall, and acquire the homogeneous refringent appearance which characterizes the spores of the greater number of the Mucorineæ. At the same time the intersporal protoplasm distributes itself so that it occupies all the space between the spores, and forms a layer between the peripheral spores and the sporangium wall. Van Tieghem considers this a process of free formation similar to that which occurs in the asceus, differing chiefly in the amount of intersporal protoplasm.

Strasburger (1880) has given an account of the more general features of the spore formation in *Mucor mucedo*. He considers that the sporogenous protoplasmic mass is cut up by cell plates analogous to those formed in cell division in the higher plants. This account is, however, very brief and incomplete.

Shortly afterwards, Büsgen (1882) studied the formation of the spores in *Mucor*. His conclusion is that the protoplasmic mass is cut up into blocks by cell plates, and that these blocks are subdivided until the final spores are reached. In this he adds little to Strasburger's account.

Léger (1896) published a paper intended to fill the gaps in our knowledge of the spore formation in the Mucorineæ. This paper is quite comprehensive, dealing with nearly all the principal genera. Léger studied the spore formation partly by means of sections of material embedded in collodion, but largely by examining the sporangia in toto or by crushing them under a cover glass. His results agree entirely with those of Van Tieghem. He finds that all the forms investigated agree in having the protoplasm divided at once into granular portions separated by nongranular plates. Later, the granular masses are surrounded by walls and become the spores, while the nongranular plates form the intersporal protoplasm.

In the case of *Rhizopus nigricans*, Léger finds that when the spores are first formed they are separated by thin membranes only. How these membranes originate he does not make clear. The intersporal substance appears a little later after the spore walls are formed. In this respect *Rhizopus* differs from all the other forms investigated.

In his description of the formation of the columella, Léger states that the contents of the sporangium are easily seen to be differentiated into a lighter and a denser portion. These are then separated by a columella wall, the lighter part being included in the columella and all the denser part remaining outside. Just how the protoplasm is divided and the wall formed he does not tell us. He states that the nuclei in the spores are oval, while those in the columella are spherical. As the spores ripen the cytoplasm disappears from the columella and the nuclei, reduced to nucleoli [sic], remain adhering to the inner surface of the columella wall.

The nucleus is essentially the same in all the forms which Léger describes. It consists of a nucleolus surrounded by a clear zone which does not stain, and outside of this by a distinct nuclear membrane. The nucleoli are described as so many times larger relatively than I have found them that I am entirely unable to credit his results. The nuclei, also, as he figures them, are much too large and contain no chromatin.

Thaxter (1897) has done the most to clear up our knowledge of the spore formation in the Syncephalidæ. He states that he was earlier

inclined to accept the view of Fischer (1892), which is that in such forms as *Syncephalis* the spores borne in a single row are formed exogenously by constriction like conidia, the wall of the fruiting body forming part of the spore wall, and that this body can not, therefore, be considered as a sporangium homologous with that of *Mucor*. After a thorough study of *Syncephalastrum* and *Syncephalis*, however, he accepted the "sporangial" theory, and brings very conclusive evidence to support his results. In *Syncephalastrum racemosum* he finds that the contents of the cylindrical cells that are to form the chains of spores are divided into spores, not by gradual constriction from the surface inward, but simultaneously by a hyaline intersporal substance. Walls are then formed around the individual spores entirely within and distinct from the wall of the mother cell. By crushing these spore rows under a cover glass he was able to force the spores out in a perfect condition, leaving the walls of the sporangia empty and intact except for their ruptured tips. This is conclusive evidence of the endogenous formation of these spores. Furthermore, in many cases he finds that the spores are borne, not in single rows, but more or less irregularly, the diameter of the sporangium being somewhat greater than that of a single spore. In such cases the planes of separation are oblique, or even parallel, to the long axis of the sporangium. In such a form as this Thaxter finds an intermediate stage between the spherical sporangium of *Mucor* and the cylindrical one of *Syncephalis*, the supposed absence of which was used by Fischer as evidence against the homology of the two.

In *Syncephalis*, Thaxter finds that the separation of the protoplasm into spores is quite different from that in *Syncephalastrum*. He investigated an undescribed species from Liberia, and also *Syncephalis pycnosperma*, and finds that in both cases the protoplasm is cut progressively from the surface inward by "intermediary zones," each of which is made up of an inner nonstainable part, and an outer one that takes stains readily. The spore wall in both species is distinct from the sporangium wall and forms close around the protoplasm, excluding the intermediary zones. In the undescribed species these zones remain until the spores are ripe and then deliquesce, while in *Syncephalis pycnosperma* the stainable portion breaks up into a refractive oily substance and the nonstainable part forms a thick permanent layer around the spore wall and gives to the spores their peculiar shape.

Harper (1899) has described the spore formation in *Piptocephalis* and *Sporodinia* of the Mucorineæ, and also in *Synchitrium* of the Chytridiaceæ. The processes in these widely separated forms show many interesting points of similarity.

In *Synchitrium*, Harper finds that the "initial cell" contains at first one comparatively large nucleus, which, as the cell reaches nearly its

full size, divides rapidly to form a vast number of smaller daughter nuclei. This multinucleated mass of protoplasm is then divided into comparatively large blocks by narrow furrows, cutting progressively inward from the periphery. These furrows cut inward at nearly right angles to the periphery, but, as seen in surface sections, they intersect each other at almost every angle. They are so narrow that they appear in section as single lines which push aside the vacuoles, arranging them in a row on either side. In case the sporangium is slightly shrunken in fixing, however, they appear as slightly separated surfaces. As these cleavage furrows grow deeper they branch, curve, and intersect each other until the whole mass is divided into multinucleated pieces. These are then divided into uninucleated pieces by furrows cutting inward from their surfaces.

The nuclei then divide until there are usually from 8 to 12 in each piece. Without further cleavage these multinucleated protoplasmic masses then enlarge somewhat, secrete a protective wall, and become the spores. They then go into a resting condition until germination.

In *Pilobolus*, Harper traces the entire development of the sporangium. He finds that when it has reached a considerable size its contents are divided into three parts—a central vesicle of cell sap, which, from the absence of a smooth, rounded surface, can not be considered as a central vacuole; outside this, a thin layer of spongy protoplasm with numerous nuclei; and outside this layer, extending to the sporangium wall, a much denser mass of protoplasm, also containing many nuclei and a few rounded vacuoles. In the spongy protoplasm, and running parallel to the sporangium wall except at the lower side where it extends to the periphery, a dome-shaped layer of vacuoles then appears. These vacuoles are at first round, but later they become flattened parallel to the surface of the sporangium until they are disk-shaped. They finally fuse, edge to edge, to form a cleft, which, with the aid of a circular furrow cutting upward through the spongy protoplasm until it meets the lowest vacuoles in the series, cuts out the columella. This columella is bounded at first by only a plasma-membrane, outside of which is a more or less open cleft. Later the columella wall is formed in this cleft. It has its dome-shaped outline from the first, and does not begin as a cross wall at the base of the sporangium, being rounded upward later by pressure of turgor from below, as is described for *Mucor* in most standard text-books. (See Bessey's text-book, p. 236.)

The spore plasm is then invaded by surface furrows cutting progressively inward. These are much like those in *Synchitrium*, but wider, owing to the more shrunken condition of the protoplasm during the process. While this is going on, the vacuoles in the spore plasm become sharply angular, and these angles, continuing outward as furrows, cut into each other and into the furrows from the surface,

thus aiding in the cleavage. The whole mass is thereby reduced to blocks of varying sizes which are, as in *Synchitrium*, progressively cut down to uninucleated pieces. As in *Synchitrium* also, these protospores are pressed tightly together by turgor.

The nuclei then divide until there is a considerable number in each piece of protoplasm. This division is followed by successive constrictions of the nature of bipartitions until a binucleated stage is reached. Each piece then surrounds itself with a wall and is a mature spore. The later phases of the process—i. e., from the protospore to the mature spore—Harper regards as an embryonic development.

In the subdivisions of the protospores, Harper notes that the protoplasm in advance of the cleavage furrows becomes clear and nonstainable, forming a hyaline zone in the plane of constriction, as though the denser part of the protoplasm drew away from this region toward the nuclei, leaving only a clear liquid substance behind. In the earlier stages of cleavage, however, both in *Pilobolus* and in *Synchitrium*, such a differentiation of protoplasm in advance of the cleavage furrows does not take place.

Here, as in *Synchitrium*, the entire protoplasm is included in the spore, there being no intersporal protoplasm. There is a slime excreted to fill the spaces between the spores, but it is not protoplasm.

In *Sporodinia* the process is in many respects much like that in *Pilobolus*, but there are some striking differences. The sporangia here are much smaller and are composed of two parts, the outer and upper part being filled with dense protoplasm, while the central and lower portion is occupied by a foamy protoplasm, there being no large opening filled with cell sap as in *Pilobolus*. The vacuoles that cut out the columella are much larger than in *Pilobolus*, and are arranged on the line, as it appears in section, between the two kinds of protoplasm. They fuse laterally to form a curved cleft, but no surface furrow cutting in to meet them has been observed. The spore plasm is then divided into blocks by furrows cutting from the columella cleft outward and from the surface inward, but here the cleavage process ceases. No uninucleated stage is ever reached. These protoplasmic blocks contain numerous nuclei, and round off and are covered with a cell wall. They are then the mature spores. This is a considerable abbreviation of the process in *Pilobolus*, and there is a corresponding shortening in the time required for developing the spores in *Sporodinia*.

The nuclei in all three forms are made up of the same parts as those in the higher plants. There is a nucleolus surrounded by a zone filled with nuclear sap and chromatin, the whole being enveloped in a nuclear membrane. A point well worthy of consideration is that the nuclei are in a resting condition during cleavage.

Hans Bachmann (1899) has described the entire structure and

development of a new species of *Mortierella*. Though the paper was published very recently, little improvement over the older writers is shown in the matter of technique. He has not, so far as he states, made any sections of the sporangia.

By a study of entire sporangia he finds that the surface comes to be marked out into polygons separated by rather broad bands of an even width. These markings he interprets as representing a surface view of polyhedric masses of protoplasm which are destined to become spores, separated by layers of intersporal protoplasm.

Plasmolyzing agents in some cases cause the sporangium to contract as a unit and not as individual polygons, showing that each is not yet entirely surrounded by an osmotic membrane.

Gentian violet stains the material between the polyhedrons; the formation of the violet lines is progressive, as is shown by the fact that in some cases they are short and do not extend over the entire sporangium, but radiate from various points. In this, Bachmann makes a decided advance over Léger, but still he apparently fails to grasp the most important point—that these blue-staining lines represent cleavage furrows filled with the stain.

METHODS.

The mold *Rhizopus* was first obtained in mixed cultures by exposing moistened bread for a few minutes to the air of the laboratory. To obtain pure cultures, a few sporangia were carefully transferred from the original cultures to slightly moistened bread, which had been exposed an hour or so on two or more successive days to a temperature of from 60° to 65° C. in a steam sterilizer. In from one to two days after inoculation the stolons began to appear on the surface of the bread, and in another day there were a considerable number of sporangia formed.

The cultures of *Phycomyces* were obtained from Ann Arbor, Mich., through the kindness of Dr. J. B. Pollock. This mold was grown either upon sterilized bread or nutrient agar. From these cultures small bits of mycelium were cut out (below the surface of the substratum in the case of *Phycomyces*) and instantly immersed in the fixing fluid. After remaining in this about twenty-four hours, they were washed for a few hours in running water, dehydrated by running through grades of alcohol, cleared in xylol or chloroform, and embedded in paraffin.

The sections were cut on a Jung, or a Reinhold-Giltay microtome, usually 4 μ thick, but sometimes 2 μ, and were fastened to slides with albumen and glycerine. They were then stained with Flemming's triple stain (safranin, gentian violet, and orange G), then dehydrated, cleared with clove oil or bergamot oil, and mounted in Canada balsam. If the right exposures are given to these stains, the cytoplasm

appears orange, the chromatin blue, the nucleolus and proteid crystalloids red, and the cell wall either blue or orange.

For fixing fluids the mixtures of Flemming, Hermann, and Merkel were used with very good results. Eisen's fluid gave some very fine results, but was little used. An exposure of one hour to Flemming's fluid, followed by twelve to twenty-four hours in Merkel's fluid or chrom-acetic acid, gave especially fine preparations, not being so much blackened as when exposed longer to the osmic acid.

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RHIZOPUS NIGRICANS Ehrbg.

The general morphology of *Rhizopus* has been very well described by the earlier authors.

The spore in germinating sends out a tube which branches until a tangled mycelium is formed in the substratum. This mycelium sends up from various points aërial hyphæ, which are erect at first and form a delicate white growth in the cultures. After these hyphæ reach the height of one or two centimeters they bend over and grow horizontally along the surface of the substratum.

When one of these stolons has grown in this direction for a short distance, it forms a swelling at the apex two to four times the diameter of the stolon, and out of this grow from two to six branches, one of which is in reality a continuation of the stolon, while the others grow into sporangiophores. (Pl. I, fig. 1.) If this swollen portion of the stolon comes in contact with the substratum or the sides of the culture dish, a few rhizoids are sent out which firmly anchor it, and, in case they penetrate any nutritive substance, these doubtless aid in nourishing the sporangiophores. The stolon continues growing out and forming these groups of sporangiophores at intervals, and finally ends with such a group at the apex. Each sporangiophore bears a single spherical sporangium.

In healthy stolons, especially if they are growing rapidly, the protoplasm is almost continually streaming in one direction or the other. This has been fully described by Arthur (1897), who considers that it is principally due to evaporation of moisture from the surface of exposed parts, together with the constant taking in of water by the hyphæ that are in the substratum. In his conclusion he expresses the opinion that "the movement is an incidental feature in the life of the plant." Further mention of this paper will be made in connection with the distribution of the protoplasm in the sporangium.

The growing ends of the stolons are densely crowded with protoplasm containing many nuclei. This condition prevails for some distance back in the stolons (Pl. I, fig. 2), but as we follow back toward the older part the protoplasm is more and more permeated with cell sap, and at last we find a region where there is nothing but a wall filled with cell sap, so far as we can distinguish from a surface view of living material. In stained sections, however, as shown in Pl. I, fig. 3, it can be seen that there is still a thin layer of protoplasm lining the wall, and strands or even small masses of it in the center. In parts as old as that shown in the figure, the nuclei have begun to disintegrate somewhat, and appear as tiny red-staining masses of various shapes. (Pl. I, fig. 4.)

The young sporangiophores, like the ends of the stolons, are densely crowded with protoplasm and nuclei, and even the lower part of the older ones is never entirely devoid of protoplasmic contents, as is stated by Léger, but retains a structure very much like that in the stolons.

As the sporangiophore reaches its full length it begins to swell out at the tip into a tiny round body, the future sporangium. The contents of this are at first evenly distributed, being equally dense in the center and at the periphery, but before it has reached half its final size the protoplasm begins to be decidedly dense toward the sporangium wall, while in the center it is of a much looser structure. Pl. I, fig. 5, shows the distribution of the cytoplasm and nuclei at this stage. There are also present a few crystalloids. They seem often to be in tiny clear vesicles, but whether or not these are ordinary vacuoles I can not be certain. These crystal-like bodies vary much in size, and as a rule increase in number as the sporangium gets older. It is quite noticeable, however, that they are entirely confined to the central part of the sporangium.

The nuclei are so small that they appear only as dots in a drawing of the size of Pl. I, fig. 5. Their structure can, however, be clearly made out with higher magnification, and it is to all appearances precisely like that of those shown in Pl. II, fig. 9, which will be described later.

The cytoplasm in young sporangia, it will be observed, is quite dense next the sporangium wall, but gradually becomes less dense toward the center, where it is of a very loose spongy structure, containing many vacuoles of considerable size. There is at this stage no sharply defined boundary between the denser and the less dense parts of the cytoplasm, but a gradual transition from center to periphery. The denser layer does not, however, extend quite to the sporangiophore at the base of the sporangium. (Pl. I, figs. 5 and 6.)

At this time also there is a very marked streaming of the protoplasm up the sporangiophore into the sporangium. These currents appear

as a bundle of strands, which in optical section spread fan-like as they enter the sporangium and extend toward the periphery. Many of these streams, particularly at the sides, extend nearly to the sporangium wall, as seen in Pl. I, fig. 5. Harper (1899) has described each individual current in *Pilobolus* as having "marked a path for itself through the protoplasmic structure. It is marked by continuous delicate films, quite distinct from the spongy structure of the adjacent plasma." These surrounding films, as the writer has seen them in *Rhizopus*, are of a more hyaline and homogeneous appearance than either the currents or the surrounding cytoplasm.

The nuclei in these currents are much elongated in the direction in which the currents run and I have not been able to differentiate the parts, the nucleolus and chromatin both staining red.

As the streaming continues the protoplasm at the periphery becomes denser, and there appear clearly differentiated layers within the sporangium. The beginning of this differentiation is not simultaneous throughout the protoplasm. It appears at certain points approximately equidistant from the periphery, between which and the periphery the thickening of the protoplasm forms a dense zone lining the sporangium except at the base, where its inner boundary line gradually extends to the periphery. In the stage shown in Pl. I, fig. 6, this boundary line is not perfect, but somewhat broken, admitting thin streams of loose protoplasm from the interior of the sporangium. Inside this zone and of about one-third its thickness is a semitransparent layer consisting of loose protoplasm like that which fills the interior of the sporangium, but clearer and less granular, and taking the orange stain less strongly than the latter. In structure it resembles the thin films about the streams previously mentioned. The cytoplasm inside this semitransparent zone and occupying the central and lower part of the sporangium is of a loose, spongy, much-vacuolated structure, containing scattering nuclei and a considerable number of proteid bodies. There are no marked protoplasmic strands indicating currents in the center of the sporangium, though the writer has often found them in later stages; but radiating from the central part of the sporangium and passing from it through the clear zone to the denser plasm are many very slender strands marking the paths of currents. These currents bear nuclei and seem to represent a very late stage of the migration of cytoplasm and nuclei toward the periphery. Some of these streams enter the openings in the denser plasm, while others run against its inner surface. This streaming goes on until the inner boundary of the denser plasm is at all points sharply defined. This boundary does not consist of a membrane or of any differentiated layer.

The denser plasm at this time contains only a very few vacuoles of any considerable size, but under very high magnification it can be seen

that there are very many exceedingly small ones, with definitely rounded outlines. Most of these are scarcely larger than the nuclei, and some are much smaller. They can not, therefore, be shown in a drawing on so small a scale as Pl. I, fig. 6. They are, however, essentially the same in size, number, and distribution as those shown in Pl. II, fig. 9.

Thus far, except for the arrangement of the cytoplasm and nuclei, we have had no phenomena in the sporangium that even suggest cell division, unless possibly it be the clear zone. The greater part of the more solid portion of the cytoplasm has formed itself into a layer at the periphery. Nearly all of the nuclei also have migrated into this portion of the sporangium, and are distributed irregularly throughout the dense cytoplasm. They are not even approximately equidistant from each other, nor are they often, if ever, in actual contact, though Léger states that such is very frequently the case. How he could determine the normal distribution of the nuclei from crushed sporangia is difficult to comprehend.

As soon as the protoplasm is distributed as has been described, the separation of that which is to be included within the columella from that which is to form the spores begins. The columella is not at first a flat cross wall at the base of the sporangium which is later pushed up by turgor to its characteristic dome shape, as it is currently described as doing, but is laid down in essentially the same fashion as described by Harper (1899) for *Pilobolus*. There first appears in the denser plasm a single layer of spherical vacuoles (Pl. II, fig. 7) running parallel to its inner surface. The layer of the denser plasm inside the system of vacuoles is usually from one-fifteenth to one-twentieth as thick as the layer outside. Apparently these vacuoles are formed by the enlargement of the very minute ones already mentioned that lie in this region, rather than by the migration of previously enlarged vacuoles. In sporangia in which this layer of vacuoles is only partly formed there are usually a few large vacuoles arranged in the layer, and between them are smaller ones, varying in size down to the smallest in the sporangium (Pl. II, fig. 7). This leads one to believe that the vacuoles in this layer are essentially like the others in the sporangium and in the mycelium. These vacuoles and all others in the sporangium agree with those of *Pilobolus* and *Sporodinia* in being devoid of all stainable contents (Pl. II, fig. 7), in which respect they differ strikingly from those of *Phycomyces*, described later.

The vacuoles are at first spherical, or nearly so, but soon begin to flatten, their long axes being parallel to the inner surface of the denser plasm. By this flattening they become disk-shaped, as in Pl. II, fig. 8, and the edges of adjacent ones come in contact and fuse, forming a narrow curved cleft in the protoplasm. At the same time a circular furrow begins to cut upward from the surface of the protoplasm at

the base of the sporangium through the denser plasm (Pl. II, fig. 8). This furrow increases in depth until it reaches and fuses with the lowest vacuoles in the layer. Thus the protoplasm of the sporangium is divided into two distinct portions destined to perform radically different parts in the further life of the plant. That outside the cleft is to be entirely cut up into spores, while that inside is later to be surrounded by the columella wall and plays no direct part in reproduction. The former I shall distinguish as the spore-plasm and the latter as the columella-plasm. It will be noted from what has been already said and from Pl. II, figs. 7 and 8, and Pl. III, figs. 10 and 12, that the columella-plasm includes all the looser plasm in the sporangium and also a thin layer of the denser plasm.

One might have expected from Pl. I, fig. 6, that the columella wall would be laid down in the clear zone shown in that figure, but that such is not the case there is no room for doubt. The writer has preparations in which this zone is still almost as marked as in the figure mentioned, while the columella cleft is forming in the denser plasm. Pl. II, fig. 8, and Pl. III, fig. 10, show that the outer part of the looser plasm is still somewhat clearer than that in the center, though the paths of the currents have become almost obliterated. The time for the disappearance of the currents varies greatly in different sporangia.

There is no visible difference while cleavage is going on between the denser plasm inside the layer of vacuoles and that outside, nor is there any differentiation of the cytoplasm between the vacuoles or in advance of the surface furrow, such as Harper found in the late subdivisions of the protoplasm of *Pilobolus* and in the last stages of cleavage of *Fuligo* (1900).

While the cutting out of the columella is going on, the sporangium gives every appearance of having only slight turgidity. The cleft in the protoplasm is always quite wide—at least in certain places. When, however, the cleavage is complete, the protoplasmic masses increase in volume and become strongly turgid again, causing the two protoplasmic surfaces lately separated to become pressed together so tightly that only by the closest study can one follow the cleft throughout its entire extent.

In case the spore cleavage, which will be described later, begins before the columella cleft is completed, as often occurs, this period of turgidity is postponed until after the spores are entirely cut out.

It will be noted that when first formed the cleft around the columella is bounded by two protoplasmic surfaces. When these surfaces become tightly pressed together by the turgor in the sporangium, one might expect them to fuse into a continuous mass of protoplasm again, there being no wall between them at this time. Indeed, such a phenomenon was described by Büsgen (1882) in the formation of the

spores of the Saprolegnieæ. It is not, however, surprising that with the technique used in those days he should fail to see that there was still a distinct boundary between the closely packed spores.

When the period of turgor relaxes a little the two surfaces generally separate slightly, but at irregular intervals points are often found where they still adhere, forming tiny conical projections, whose apices are for a short time in contact.

In the behavior of these two protoplasmic surfaces we have considerable additional evidence for the existence of a definite plasma-membrane.

Even before the cutting out of the columella takes place the nuclei of the looser protoplasm begin to disintegrate. In very young sporangia all the nuclei have the same normal structure, but in the one shown in Pl. I, fig. 6, for example, they are clearly suffering disintegration in the center of what is to become the columella-plasm, though out near the denser plasm they retain their characteristic structure, often until the spores are nearly ripe. (Pl. III, fig. 13, *a*.)

It might be suggested that the nuclei in the center of the sporangium are not well fixed, but these sporangia are so small and thin-walled that I can not believe, with all the cytoplasm and the greater part of the nuclei having a perfectly normal structure, that the difference in appearance of these nuclei is to be attributed to poor fixation, especially as it is essentially the same for all the best fixing fluids used.

The first sign of disintegration is the appearance of a red-staining mass on one side. As the process goes on, the whole nucleus comes to appear as a slightly shrunken, homogeneous mass, often irregular in shape, and staining the same shade of red as the crystalloids. It might be argued that these red-staining bodies are crystalloids whose substance is being dissolved, but I have found very good evidence that such is not the case. As shown in Pl. III, figs. 11 and 13, there are all stages of disintegration between the almost perfect nuclei and the most shrunken and angular ones. On the other hand, all the crystalloids in these sporangia, so far as could be observed, are perfect in shape, none showing notches or marks of corrosion, such as we should expect to find if they were being dissolved. Furthermore, the crystalloids seem to be forming rather than dissolving, judging from their greater number and size in the older sporangia.

In Pl. III, figs. 11 and 13, *a* represents a nucleus with normal structure lying just inward from the denser plasm, while *b*, *c*, and *d* lie nearer the center and are breaking down. In no sporangia as old as that shown in Pl. I, fig. 6, have I found nuclei in or near the center of the looser plasm in which nuclear membrane, chromatin, and nucleolus could be distinguished. These nuclei do not entirely disappear during the life of the plant, nor would it be at all accurate to say, as Léger has done, that they are "reduced to a nucleole."

The formation of the spores usually begins after the columella cleft is complete, although in some instances (as in Pl. II, fig. 8) somewhat previous to that, but always before the laying down of the columella wall. Spore formation does not take place in the manner described by Van Tieghem and Léger—by the simultaneous differentiation of plates of hyaline nongranular protoplasm cutting the spore-plasm into polyhedric blocks—nor by the progressive differentiation of such plates from lines on the surface of the protoplasm, as described by Bachmann (1900). In the scores of sporangia sectioned in all stages of development the writer has not found at any time even the slightest indication of such a differentiation of the protoplasm into granular polyhedric masses with nongranular plasm between. The first indication of the division of the spore-plasm is the formation of furrows at the surface, which cut progressively inward. (Pl. II, figs. 8 and 9.) These furrows are not broad, as in *Pilobolus*, nor are their sides closely pressed together, as in *Synchitrium*. They cut in at very different angles to the surface of the sporangium, and pass between, and often very close to, nuclei and vacuoles. (Pl. II, fig. 9.) They usually branch or curve at a short distance inward from the surface, and by cutting into and fusing with neighboring furrows cut out small pieces of the surface layer of the protoplasm of the sporangium. These pieces are almost always the definitive spores, lacking only the walls. Only a few of the larger ones are further divided up. There is no uninucleated stage in the spore formation of *Rhizopus*, as in *Pilobolus*, it being like *Sporodinia* and *Phycomyces* in this respect. These spores are at first somewhat angular in shape and contain exactly the same number of nuclei (2 to 6) as when ripe, there being no nuclear division at any stage of their existence previous to germination.

The nuclei of the spore-plasm during all stages of cleavage are in a resting condition. (Pl. II, fig. 9.) Each consists of a nucleolus, or occasionally two nucleoli, which in my preparations is stained a deep red, surrounded by a zone of evenly granular, blue-staining chromatin, the whole being bounded by a definite nuclear membrane. Both in the spore-plasm and in the columella the nuclei are spherical or very slightly ovoid until they begin to disintegrate. They are relatively more numerous in some sporangia than in others, which may possibly be due to differences in the moisture supply, wet cultures making looser and more bulky cytoplasm than drier ones.

The vacuoles of the spore-plasm, which are for the most part exceedingly minute, as can be seen by a comparison with the nuclei in Pl. II, fig. 9, do not become angular and assist in dividing the protoplasm here as in *Pilobolus* and *Phycomyces*. They retain their rounded form throughout the entire process of cleavage, even when furrows cut very close to them. As previously stated, they contain nothing but ordinary cell sap.

After the surface furrows have cut inward for a considerable distance, a few similar furrows begin to cut outward from the columella cleft, which as yet contains no wall. (Pl. III, fig. 10.) With the meeting of these two systems of furrows the cleavage is practically complete.

During the process of spore cleavage the protoplasm is slightly shrunken, apparently because of the giving off of water. The furrows are more or less open and filled with clear cell sap only. (Pl. II, fig. 9.) As soon, however, as the cleavage is complete, the spore mass becomes strongly turgid again, and each spore so increases in volume that all are pressed tightly together and the furrows are entirely closed, so that with the Zeiss 2 mm. immersion objective, 1.30 aperture, and No. 18 compensating ocular, they appear in optical section as single lines and are very hard to trace through the dense spongy cytoplasm. The spores are thus made sharply angular, but later they round off, leaving little spaces between them.

The formation of the columella wall usually begins before the spores are entirely cut out, but it does not reach its definitive thickness until they are nearly ripe.

As seen in Pl. III, fig. 12, these spores have no regular system of arrangement whatsoever, and the writer can not find the slightest ground for Corda's view that they are in radial rows.

As already stated, the spaces between the spores contain at first absolutely nothing except cell sap. There is no trace of any intersporal protoplasm, such as has been described by the earlier authors and considered as homologous with the epiplasm of the ascus.

The spores of *Rhizopus* are at first angular and covered by only a plasma-membrane, but soon round off and a firm wall is formed about them.

During this process of ripening a homogeneous slime is excreted by the spores, which fills up the spaces between them. In such exposures to the triple stain as best bring out the cytoplasmic and nuclear structures this intersporal slime does not stain at all, and for this reason the writer has left it an empty space in Pl. III, fig. 12. By a longer exposure to the violet it is readily brought out as a smooth bluish mass filling up the spaces between the rounded spores.

There is no special mechanism for the discharge of the spores in *Rhizopus* as in *Pilobolus*. There is, however, an inner layer of the sporangium wall that can not readily be differentiated from the rest of the wall in specimens fixed in the killing fluids of Flemming and Merkel; while in those fixed in Eisen's fluid and stained in the triple stain it is very readily distinguishable from the outer layer by its lighter blue color, the boundary between the two being sharply defined. Pl. II, fig. 7, is therefore the only one in the writer's series in which he could show the separate layers of the sporangium wall.

The inner layer is somewhat thicker than the outer, both being of an even thickness except for a little space around the sporangiophore where the inner one thins out and disappears. Whether or not this is homologous with the "collar" of *Pilobolus*, the writer can not be certain.

The spores are set free by the bursting of the sporangium wall, without its being thrown off. Whether or not the inner layer of the wall swells by the absorption of water and bursts the outer layer the writer has not determined. The writer has never found this inner layer on sporangia as young as that shown in Pl. I, fig. 5, nor in the walls of the mycelium.

The ripe spores as they escape from the ruptured sporangia are mostly ovoid in shape and of varying sizes. Their walls are marked with longitudinal ridges, as may be seen in Pl. III, fig. 14.

PHYCOMYCES NITENS Kunze.

Unlike *Rhizopus*, the sporangiophores of *Phycomyces* are borne singly, springing directly from the mycelium. When the sporangiophore is yet only a few millimeters long, the apex begins to swell out into a sporangium in the same manner as that described for *Rhizopus nigricans*. As the sporangium enlarges the sporangiophore elongates, pushing up the former farther and farther from the surface of the substratum. The spores are formed when the sporangiophore is about 2 cm. long, and it is then that the sporangium has its maximum diameter.

As shown in Pl. IV, fig. 15, there is the same streaming of cytoplasm and nuclei up the sporangiophore and out toward the periphery of the sporangium as in *Rhizopus nigricans*.

As can be seen by a comparison of Pl. IV, fig. 15, with Pl. I, fig. 7, the cytoplasm in the young sporangium of *Phycomyces* is more coarsely granular than that of *Rhizopus* and takes the stain much more deeply.

The most noticeable difference between the young sporangium of *Phycomyces* and that of *Rhizopus* is that in *Phycomyces* there are many more large round vacuoles which, as they move outward toward the periphery of the sporangium, become filled with a visible content. (Pl. IV, fig. 15.) This content appears in sections stained with the triple stain as a bluish homogeneous body of the same shape as the vacuole but somewhat smaller in diameter, lying in the middle of the vacuole, with a clear zone between it and the vacuolar membrane. (Pls. IV and V, figs. 15 to 22.) This content begins, not as a very minute, sharply-staining body which grows larger and larger in diameter, but as a faintly-staining mass which, as it grows older, becomes more dense and takes the stain more strongly. In the youngest stage it appears quite as large in proportion to the size of the vacuole in which it lies as when it becomes older. (Pl. IV, fig. 16.) It forms in

the vacuoles *after* they have entered the sporangium—never, so far as I have observed, appearing in those of the mycelium or sporangiophore, and rarely in those of that part of the sporangium which lies close to the mouth of the sporangiophore. The younger stages of their formation are shown in Pl. IV, figs. 15 and 16, while in Pls. IV and V, figs. 18, 19, and 20, they have reached their maximum density.

As the protoplasm streams up into the sporangium and out toward the periphery, there is at first a gradual transition in density from the center outward, precisely as in *Rhizopus* at the same stage. (Pl. IV, fig. 15.) A little later, however, as in Pl. IV, fig. 17, it is divided into three regions, differing in density. The outer region or layer is very dense and takes the stain strongly. Inside this is a second layer, which is considerably less dense and stains less strongly. Inside this second layer and occupying the central part of the sporangium is a region of very loose and much vacuolated protoplasm which takes the stain scarcely at all. Between the interior region and the second layer the the differentiation becomes very sharp, but, as in *Rhizopus*, there is no wall or membrane of any kind between them. Between the second and the outer layers, however, the transition is at first very gradual (Pl. IV, fig. 17), but becomes more and more sharp as the sporangium grows older. I have never found in *Phycomyces* a stage such as is shown in Pl. I, fig. 6, which occurs regularly in *Rhizopus*. It is possible that this second layer is homologous with the semitransparent zone that has the same relative position in the sporangium of *Rhizopus*. I have not regarded it as such, however, as it is of so much greater relative density and contains no delicate strands representing currents. It is interesting in this connection to compare Pl. I, fig. 6, with Pl. IV, figs. 17 and 18.

The nuclei are at first about evenly distributed in the outer and second layers, but in the interior there are very few, or for a short period in the development of the sporangium none. (Pl. IV, figs. 17 and 18.)

None of the vacuoles in the interior region of very loose protoplasm or in the inner part of the second layer has the stainable content mentioned above. Practically all of the larger ones in the outer dense layer contain this substance, however, as also do most of those in the outer part of the second layer. (Pl. IV, fig. 17.) Between these larger vacuoles are very small ones which contain nothing that takes the stain. (Pls. IV and V, figs. 15–24.) The difference in the destinies of these two kinds of vacuoles will be seen later.

As may be seen from Pl. IV, figs. 15, 17, and 18, and Pl. V, fig. 19, the vacuoles that contain the stainable substance are very numerous, taking up a considerable portion of the space in the sporangium and lying very close together, often two or more being in actual contact, their clear zones being separated by only the vacuolar membranes. (Pls. IV and V, figs. 15, 17, 18, 19, and 20.) In such cases

the vacuolar membrane is isolated from the remainder of the protoplasm for a little space, and may readily be seen and studied by itself. (Pl. V, fig. 20.) It is very thin and homogeneous, taking the violet stain very slightly, which gives it a faint blue color. When two vacuoles are thus in contact they are usually flattened against each other, so that the membrane between appears in optical section as a thin, straight line. In such cases the contents are often flattened on that side to conform to the shape of the vacuole. (Pl. V, fig. 20.)

A considerable number of the nuclei that are in the second layer when it is first formed migrate into the denser plasm, and the differentiation between the two layers becomes more distinct. Then a layer of vacuoles, practically all having stainable contents, becomes arranged in a dome shape in the denser plasm and running parallel to its inner surface. (Pl. IV, fig. 18.) These vacuoles flatten out, become disk-shaped, and fuse edge to edge to form a dome-shaped cleft in the denser plasm, as in *Rhizopus* and *Pilobolus*. (Pl. V, fig. 19.) It is interesting to note that as the vacuoles flatten, the content flattens also, so that its surface remains always more or less parallel to the vacuolar membrane. (Pl. V, fig. 19.)

So far as I have been able to observe, there is never a surface furrow that cuts inward to meet the lowest of the layer of vacuoles, as is the case in *Pilobolus* and *Rhizopus*. In this respect *Phycomyces* appears more like *Sporodinia*. The layer of vacuoles begins so very near the surface of the protoplasm (Pl. V, fig. 19) that if there is such a surface furrow it must be very shallow indeed. I have never found any evidence of its existence.

When the vacuoles of this layer have entirely fused, edge to edge, the separation of the columella is complete. There is at first no wall—simply a cleft bounded by plasma-membranes. The contents of all the vacuoles that make this cleft have now fused, forming a layer of slightly uneven thickness separating the outer surface of the columella plasm from the inner surface of the spore-plasm. All the very loose interior protoplasm, the second layer, and a small part of the denser plasm are included within the columella, while the greater part of the denser plasm goes to form the spores.

As soon as the differentiation of the columella is complete, or in exceptional cases a little before, the formation of the spores begins. Here we get a most striking difference between *Phycomyces* and *Rhizopus*. The large round vacuoles in the spore plasm begin to lose their rounded form and become angular. (Pl. V, figs. 21 and 22.) These angles become sharper and sharper, and appear to cut through the cytoplasm between the nuclei, and when they encounter each other fuse to form irregular clefts. The cytoplasm in advance of these vacuolar furrows shows no visible differentiation, but remains of an even density throughout the entire spore-plasm during the whole process of

cleavage. (Pl. V, figs. 21 and 22.) So far as the writer has been able to observe after a most diligent search in a very large number of sporangia in all stages of spore formation, there are never surface furrows cutting into the spore-plasm at any point. The angles from the vacuoles may often be seen cutting out to the surface of the spore-plasm. (Pl. V, figs. 21 and 23.) Furrows also cut into the spore-plasm from the columella cleft and fuse with the vacuolar furrows in the spore-plasm, and thus aid in dividing the protoplasm into spores. (Pl. V, fig. 22.)

During the whole process of spore formation the nuclei are in a resting condition. They are spherical, or nearly so, and are made up of one or two nucleoli and finely granular chromatin within the nuclear membrane. (Pl. V, figs. 20–24.) They are a little larger than those of *Rhizopus*. The furrows often cut very close to them, but they give no visible sign of being in any way affected by the cleavage of the cytoplasm in which they lie. (Pl. V, figs. 21–23.) I have never observed a single case of nuclear division in the sporangium of *Phycomyces*.

The very small vacuoles described above that have no stainable contents do not take any part in the cleavage. They remain round throughout the process, even when the furrows from the larger vacuoles cut very close to them. (Pl. V, fig. 22.)

As the vacuoles that take part in the cleavage become angular the content becomes angular also, taking approximately the shape of the vacuoles, so that its surface is parallel to the vacuolar membrane, but seldom in contact with it, there being still the clear nonstainable zone between. (Pl. V, figs. 21 and 22.) As the angles of adjacent vacuoles fuse, the contents are brought in contact and fuse also, thus forming a mass filling up the spaces between the spores. (Pl. V, fig. 21.) It will clearly be seen that this mass is not protoplasm, as it originates as a secretion from the vacuolar membrane deposited inside the vacuole. It is homogeneous at the time the spores are formed, staining bluish-brown in Flemming's triple stain and containing no nuclei or other inclusions. All the cytoplasm and nuclei of the spore-plasm are included within the spores themselves. (Pl. V, fig. 21.)

There appears to be a considerable shrinkage of the protoplasm while the cutting out of the columella and the spore formation are going on, and this is followed by an increased turgidity of the protoplasmic masses, but this is not so marked as in *Rhizopus* and *Pilobolus* and the spores do not become sharply angular. This increase in turgidity of the protoplasmic masses is followed by a very marked enlargement of the small vacuoles, which did not take part in spore formation. They still, however, contain only ordinary cell sap and no stainable contents. The columella wall begins to form while spore cleavage is going on, and continues to thicken until the spores are nearly ripe.

Up to this time the spores are surrounded by only a plasma-membrane, the spore wall not yet having been formed. They now begin to round off and contract, the vacuoles become very much smaller, and the whole spore is thereby much reduced in size and surrounds itself with a wall of considerable thickness. At the time the spore wall is formed the plasma-membranes of the adjacent spores are not in contact, but are separated by the intersporal slime from the vacuolar contents.

The plasma-membranes of the spores, except in the peripheral layer, originate entirely from the vacuolar membranes, without visible change except in form. Only a part of the plasma-membrane of the spores in this layer is made up of the original plasma-membrane of the sporangium. In this respect there is a marked difference between *Phycomyces* and *Rhizopus*.

The spores vary greatly in size and in the number of nuclei. Every spore has at least one nucleus, and some have as many as twelve or perhaps more. As a rule, there are about six or eight. In Pl. V, fig. 25, *a* and *c* show the extreme sizes of the spores and *b* the usual size and shape. Unlike *Rhizopus*, the walls of these spores are smooth.

Occasionally the cleavage is interrupted before it is complete, and walls are built around partially divided masses of protoplasm before they have rounded off sufficiently to obliterate the furrows. This results in peculiar-shaped spores, such as are shown in Pl. V, fig. 26, *c*, and fig. 27.

After the spores have been formed the intersporal slime becomes foamy in appearance. (Pl. V, fig. 24.) If the sporangium be allowed to dry out and is then placed in water, this intersporal substance swells considerably and probably aids in breaking the sporangium wall. This wall is made up of two layers from a stage even younger than that shown in Pl. IV, fig. 15, though the walls of the mycelium and the sporangiophores show only one layer in stained preparations.

Owing to the great shrinkage of the spores in ripening and to the partial collapse of the columella, the sporangium is very much smaller in diameter when mature than at the time the spores are formed.

From the time of the cleavage to the ripening of the spores the sporangiophores elongate very rapidly, often reaching a length of 10 cm. or more. The ripening usually requires only a few hours.

As in *Rhizopus*, the old mycelium is not entirely empty, but contains a very thin layer of protoplasm lying close to the wall, and in this protoplasm are embedded a few nuclei. The columella also in the ripe sporangium contains a loose network of protoplasm with scattered nuclei. The nuclei, while the mycelium is young, have essentially the same structure as those in the spores, except that they often have as many as three nucleoli. As the mycelium grows older, however, they disintegrate like those of *Rhizopus*.

The writer has also studied the cutting out of the columella and the spores in *Pilobolus crystallinus* and *Sporodinia grandis*, but, as his investigations agree with Harper's account (1899), he has simply given a fuller review of his work than he should otherwise have done, and shall treat these two genera in his general discussion.

GENERAL CONSIDERATIONS.

From a consideration of the preceding pages, we find that the processes by which the spores are formed in *Rhizopus* and *Phycomyces* appear very different, and that both these forms differ from *Pilobolus* and *Sporodinia*, which two are different from each other. In other words, of the four genera of the Mucorineæ that have been most carefully studied no two are alike.

In *Phycomyces* the spore-plasm is divided into spores by vacuoles alone.[a] The furrows cutting outward from the columella cleft form no exception to this statement, this cleft being simply a fused system of vacuoles. In *Pilobolus* both vacuoles and surface furrows take part in the process. In *Rhizopus* and *Sporodinia* the work is done entirely by surface furrows and furrows from the columella cleft, the vacuoles in the spore plasm playing no part in the process. *Sporodinia*, however, differs from all the other forms in having none of the denser plasm included inside the columella, and from *Pilobolus* and *Rhizopus* in having no surface furrow to assist the vacuoles in cutting out the columella. *Pilobolus* differs also from the other three forms in that the spores in this genus only are cut down to a uninucleated stage, followed by an embryonic development consisting of nuclear and cell division.

There are some respects, however, in which all four genera agree. In all cases the protoplasm is divided progressively, the nuclei during the cleavage are in a resting state, and *all* the protoplasm in the sporangium outside the columella is included within the spore walls, the substance between the spores not being protoplasm but a slimy material excreted by it through osmotic membranes.

Harper (1899) has pointed out that this is not a process of free cell formation in the sense that the cells are cut out entirely within a larger mass of protoplasm, as in the ascus of *Lachnea* and *Erysiphe*, but is an entirely different type of cell division. He uses this as evidence against the homology of the sporangium of the Zygomycetes with the ascus. Juel (1902), however, in a very recent paper on *Taphridium* (a new genus of the Protomycetes) seems to have entirely missed this part of Harper's distinction. He refers to the action of the kinoplasmic rays as being Harper's whole distinguishing characteristic of free cell formation, and considers this insufficient grounds for such a distinction. He

[a] By this is meant not that the vacuoles are the sole and active agents of division, but that they are not assisted by surface furrows. See note to page 31.

calls the division of the protoplasm in *Taphridium* free spore formation, though he confesses that he does not understand the stage in which the spores are being cut out, and gives us no conclusive evidence that the substance between the spores is protoplasm.

Timberlake (1902) has described a process of cleavage in the formation of the swarm-spores of *Hydrodictyon utriculatum* similar to that which I have described. In this alga the protoplasm forms a layer of an even thickness around a central vacuole, and this protoplasm is divided into a single layer of spores by narrow furrows cutting from the central vacuole outward and meeting similar furrows from the surfaces.

The mechanics of this process of division present a very perplexing problem. Sections like those shown in Pl. II, fig. 8, and Pl. III, fig. 10, where cleavage is only partly complete, have an appearance that suggests the effect of cracking on the surface due to drying. If a colloidal sphere were allowed to dry by evaporation from its surface, it would crack and split in a manner much like the sporangia of *Rhizopus*. That such an explanation is not adequate for this cleavage phenomenon is clearly evident from the fact that the furrows are filled with cell sap in living specimens throughout the entire process of division. One can scarcely imagine any body cracking from drying out when the crevices are filled with a watery liquid. In any case such an explanation would not account for cleavage by angles cutting out from vacuoles embedded in the protoplasm.

An explanation that would in a measure account for the angles being pushed out from the vacuoles is that the vacuoles take up water from the surrounding cytoplasm by osmosis through their membranes, which would cause an outward pressure against the latter. If now certain parts of this membrane should become weaker than other parts, these weaker parts would be pushed out by the internal pressure. Such an explanation, however, would not account for the surface furrows, as they are not surrounded on all sides by an osmotic membrane, there being no membrane across the mouth of the furrow at the periphery of the sporangium. (Pl. II, figs. 8 and 9.) If such a membrane be present, it is so thin that it is not visible with the highest powers of the microscope, and hence it is doubtful whether it would be more resistant to outward pressure from within the furrow than the plasma-membrane and cytoplasm at the inner edge of the furrow.

That the plasma-membrane and vacuolar membrane should possess sufficient rigidity to cut into the protoplasm after the fashion of a knife is entirely foreign to our conception of these membranes.

The most probable explanation the writer has found for the mechanics of the cleavage is on the basis of local contractions of the cytoplasm, somewhat comparable to the phenomena exhibited in the naked protoplasm of amoebae and pseudopodia. In Pl. VI, figs. 28–31, the writer

has attempted to demonstrate diagrammatically the way in which such localized contractions would cut up the protoplasm in exactly the same manner actually occurring in these sporangia. The type of cleavage represented in *Piloboluss* has been chosen so that the same diagrams may be used to explain vacuolar and surface-furrow cleavage. For the sake of clearness the diagrams were made much simpler than the actual sporangia, but without changing any essential fact of structure. The lines of force caused by the contraction of the cytoplasm have been represented by arrows—red indicating a locality in maximum contraction; green, a locality that has not yet reached its maximum; and blue, a locality that has passed its maximum. Where there are wide spaces between arrows there is assumed to be little or no contraction. Dotted black lines represent planes where cleavage will take place.

For the cutting out of the columella, let us assume that after the system of vacuoles shown in Pl. VI, fig. 28, is formed, the cytoplasm at such points between but close to the vacuoles, as shown by the red arrows, begins to contract in a direction at right angles to the future columella cleft, the spore-plasm pulling toward the periphery and the columella-plasm toward the center of the sporangium. This would tend to pull the cytoplasm away from the points at the rear ends of the arrows and also to draw the general masses of the spore-plasm and the columella-plasm toward each other. This would cause pressure against the sides of the vacuoles and cause them to flatten out to fill the spaces from which cytoplasm is being withdrawn, as is shown in Pl. VI, fig. 29. At the base of the sporangium where the surface furrow is to cut in, the cytoplasm contracts in a direction approximately radial to the curve in which the furrow is to cut. This pulling causes a rift beginning at the surface of the sporangium, and the viscid plasma-membrane, ever adhering to the surface of the cytoplasm, folds in to line this rift. As the furrow cuts inward, the points of greatest contraction move inward also (Pl. VI, fig. 29), keeping always close in front of the furrow until the latter fuses with the lowest vacuoles in the system.

The principle involved in the cleavage of the spore-plasm is essentially the same. At the points indicated by red arrows in Pl. VI, fig. 30, viz, on the periphery, on the columella cleft, and on the vacuoles, the cytoplasm begins to contract in a direction approximately toward the centers of the masses of protoplasm that are to become the spores. This pulling away of the protoplasm causes rifts or furrows running into the spore-plasm from the periphery, the columella cleft, and the vacuoles, as shown in Pl. VI, fig. 31. The width of the furrows depends on the continuation of the contraction after the furrows have progressed beyond the points of contraction, i. e., on the amount of contraction that takes place at the points marked in the diagrams

by green-colored arrows. If the pulling at the sides of the furrows continues, as in *Pilobolus*, the furrows are wide, but if it soon ceases, as in *Synchitrium*, they are narrow.

It is not improbable that in the last stages of cleavage, where the spores are connected by only a slender neck, constriction like that which cuts off conidia may play a part in finishing the process.

There is little evidence that the nuclei directly influence the contraction. The direction of the contraction seems to be in general toward the center of the protoplasmic masses that are to be the spores, without regard to the distribution of the nuclei. The nuclei do, however, seem to determine to some extent just what protoplasm shall constitute each individual spore; otherwise we might have spores formed of enucleated pieces of protoplasm, and none such has ever been observed in these forms.

Viewing the cleavage from the basis of localized contraction of the cytoplasm, we do not find such radical differences in the processes involved in *Pilobolus*, *Sporodinia*, *Rhizopus*, and *Phycomyces* as appeared at first sight. In *Pilobolus* and *Phycomyces* there are large vacuoles in the spore-plasm, in the vicinity of which cytoplasmic contractions take place in such a way as to cause angles to cut outward from the vacuoles, while in *Sporodinia* and *Rhizopus* such is not the case. On the other hand, there are no cytoplasmic contractions on the periphery of the sporangium in *Phycomyces* as in the other three genera. Otherwise these four genera exhibit no essential differences in the manner of formation of the columella and spores. The difference is simply in the location of the cytoplasmic contractions.

The explanation offered for the mechanics of the cleavage in the sporangia of the Mucorineæ seems equally applicable to other cases of surface cleavage, e. g., *Synchitrium*, *Fuligo*, and some animal eggs. To illustrate this extended application of the theory the writer has made diagrams of *Synchitrium*, *Fuligo*, and the egg of the squid, indicating, by means of arrows, as in Pl. VI, figs. 28–31, the location, direction, and duration of the cytoplasmic contractions that would produce such furrows as have been observed in these forms. Pl. VI, figs. 32 and 33, are based on Harper's (1899 and 1900) figures, and Pl. VI, fig. 34, on Watasé's (1890) figure. If this view of the mechanics of cleavage be the correct one, we must regard the vacuoles as passive rather than active agents in cutting the protoplasm.[a] They have, however, a very definite and important mission to perform. In all four genera under discussion they form the greater part of the plasma-membrane for the columella and for the surface of the spore-plasm next to the columella, and in *Pilobolus* and *Phycomyces* they form the greater part of the plasma-membrane for the spores. As I have already stated, this is done by the vacuolar membrane becoming directly a

[a] See note at the bottom of page 28.

part of the plasma-membrane without any visible change except in form. The protoplasmic surface that abutted against the vacuole is the same that is later in contact with the cell sap in the clefts. The boundary of the vacuole has become directly the boundary of a part of the cleft. We have good reason, therefore, to believe that the vacuolar membrane is identical with, or at least very similar to, the plasma-membrane, and may serve the same purpose if opportunity is offered. This homology is further substantiated by the fact that the columella wall is laid down in the dome-shaped vacuolar cleft by the plasma-membranes, formed for the most part by the vacuolar membranes, and, in the case of *Phycomyces* and *Pilobolus*, the walls of most of the spores are formed by what was once a number of vacuolar membranes. If, with Strasburger (1898), we regard the plasma-membrane as kinoplasmic, we find here very strong reasons for believing that the vacuolar membrane is of a kinoplasmic nature also.

The vacuoles are, then, openings in the protoplasmic mass, less resistant to the contraction of the cytoplasm, and from which clefts may originate. In the higher plants and in the asci of the Ascomycetes we have the new plasma-membrane of the daughter cells formed by the kinoplasmic fibers. In most animal cells and in many of the algæ, as *Cladophora*, and in the formation of conidia in fungi, the new plasma-membrane originates from the old by following the constriction furrow from the surface inward. In *Phycomyces* there are neither spindle fibers nor surface furrows present during spore formation, and the kinoplasm which forms the plasma-membranes for the spores seems to be located entirely in the vacuolar membrane.

The behavior of the vacuoles in the sporangia of *Pilobolus*, *Sporodinia*, *Rhizopus*, and *Phycomyces* is of considerable interest in its bearing on the question of whether or not the vacuole can be considered as a permanent organ of the cell. Though, as already suggested, the vacuoles are probably not active agents in the division of the protoplasm, yet there can be no doubt that they do have a part to play in the process by offering places of slight resistance to the contractions of the cytoclasm, and by supplying material for the formation of new plasma-membranes around the spores and the columella. In the cutting out of the columella it is evident that the vacuoles are arranged in their definite dome-shaped system for the distinct purpose of being where they can best do their part in the process. In *Phycomyces* the early formation of the stainable substance in some vacuoles, while others remain empty, and the fact that the former go to form plasma-membranes for the spores and the columella, while the latter do not, indicate that certain vacuoles are predestined from a very young condition of the sporangium to take part in columella and spore formation.

The idea that the vacuolar membrane has special properties not possessed by the general body of the cytoplasm is by no means a new one. De Vries (1885) has shown, by treating living cells with plasmolyzing agents containing coloring matter, that the vacuole wall is an osmotic membrane like the hautschicht. He has also been able to isolate the vacuoles from the cytoplasm without breaking them, showing the wall to have some strength and elasticity, and that it retains its identity even when not surrounded by a viscid cytoplasm. The vacuoles of *Spirogyra* were often seen to divide by constriction when treated with a saltpeter solution. By long immersion in a saltpeter solution followed by eosin the vacuole wall was hardened, so that it would be broken by pressure without collapsing. De Vries concludes that there is a very strong similarity between vacuole wall and hautschicht.

Went (1888) holds that all living plant cells, with the possible exception of bacteria, Cyanophyceæ, and spermatozoids, contain vacuoles, which by division furnish all the vacuoles for the succeeding generations of cells. In *Aspergillus oryzæ* he saw both division and fusion of vacuoles. In a cell of *Dematium pullulans* he observed nine vacuoles fuse into two large ones. These then fused to form one; but before the constriction left at the point of fusion had disappeared another constriction had begun to form in another part of the same vacuole, which increased in depth until it had cut the vacuole in two again. Went expresses his belief that the wall of the vacuole plays an active part in this division. In *Cladosporium herbarum* and in the hairs on the epidermis of *Cucurbita pepo* he found that the vacuoles divide just before cell division.

Went concludes that the vacuole wall is an organ of the protoplasm ranking with the nucleus and the chromatophores, originating by the division of a previously existing vacuole, and never forming de novo in the protoplasm.

Bokorny (1893) treated living cells with a weak caffein solution and found that the vacuole wall was not killed by it, but that it contracted without losing its rounded outline, precisely as De Vries describes for vacuoles when the cell is treated with a 10 per cent saltpeter solution. Bokorny points out that, as a dilute caffein solution has but very weak plasmolyzing power, the phenomenon in this case is one of irritability, the caffein solution being the stimulus and the vacuole wall being the receptive part of the cell. A caffein solution as weak as 0.01 per cent will cause the reaction.

The work of these authors offers very strong evidence that the vacuolar membrane is at least a differentiated and specialized portion of the protoplasm, differing molecularly from ordinary cytoplasm, and having many properties in common with the plasma-membrane.

Pfeffer (1890) confirms the conclusions of De Vries and Went that the vacuole wall is an osmotic membrane very much like the hautschicht, and that it reproduces itself by division. He is able to form new vacuoles in plasmodia, however, by introducing very small particles of asparagin, and finds these to agree in all essential particulars with normally produced vacuoles. He also holds that by extensive vacuolization nearly all of the cytoplasm may be changed to "plasmahaut" (vacuole wall and hautschicht). Pfeffer, seems, however, inclined to regard both the vacuole wall and the hautschicht as the result of surface tension, and a precipitation of the surface of the cytoplasm by contact with water.

Bütschli (1892) also refuses to accept the view that the vacuole is bounded by a definite, permanent wall, and would, with Pfeffer, refer it to surface tension between the watery liquid of the vacuole and the viscid, semiliquid protoplasm; or, at most, he regards this boundary as only a precipitation membrane formed by the action of the vacuolar contents on the adjacent protoplasm.

In the part played by the vacuoles in the formation of the spores in the Mucorineæ we have additional evidence that the vacuolar membrane is a more definite structure than Bütschli regards it. The vacuolar membrane so clearly is able at times to perform the functions of the plasma-membrane that the structure and composition of the two seem identical.

The exact composition of the stainable substance in the vacuoles of *Phycomyces* is not easy to determine. In living sporangia crushed under a cover-glass it is easy to see the vacuoles more or less isolated from the cytoplasm, but no contents can be seen at any stage of development. Neither can the intersporal substance be seen in sporangia where cleavage is only partially complete. In older sporangia, however, this is clearly visible. This would suggest that this substance is in solution or very transparent in living sporangia and is precipitated in the process of dehydrating or clearing—probably by the alcohol. It appears in sections of old sporangia even before staining, no matter what fixing fluid is used. It is not readily soluble in water, as may be seen from the fact that it is visible in sections that have been soaked several hours in water.

In seeds, Wakker (1888) found that the aleurone grains inside the vacuoles begin as very minute, dense bodies, much smaller than the vacuoles themselves, afterwards increasing in size till the vacuoles are nearly or quite filled by them. As I have already pointed out, however, the contents of the vacuoles of *Phycomyces* are at the moment they first become visible quite as large in proportion to the size of the vacuole as when they become older. The substance seems to be evenly distributed in the cell sap of the vacuole, simply increasing in density as the sporangium grows older. There can be little doubt that it is a

secretion of the cytoplasm through the vacuolar membrane, and the fact that the substance is secreted only in those vacuoles which are to take part in the cleavage seems to indicate a difference, in function at least, between the membranes of the two kinds of vacuoles.

The clear zone between the body inside the vacuole and the vacuolar membrane seems to be due to the contraction of the substance in dehydration.

The fact that this substance takes so readily the shape of the vacuole or the furrow that contains it would show that in the living state it is not solid, but very plastic, if not in actual solution.

Stevens (1899) describes a gelatinous, stainable substance in the vacuoles of the oogonium of *Albugo bliti*, and seems to regard it as being used to form the walls of the oospore. He says of it: "It appears to be transferred directly from the vacuoles to the exterior of the protoplasm, there to be changed to true cellulose." Whether or not this substance is the same as that in *Phycomyces* I can not be certain. Stevens's description agrees very well with my own in that the substance takes the stain only slightly when first formed, and stronger in later stages. In *Albugo*, however, it leaves the vacuoles and goes to form cellulose walls, while in *Phycomyces* it never disappears, but forms the intersporal substance in the clefts made by the vacuoles and apparently plays no part in the formation of walls. Stevens describes this substance as occurring in figs. 91, 92, 93, and 94 of his Pl. XV, but I have been unable to find any representation of it in the places referred to. Neither does he describe the method by which it is transferred to the periphery of the oospore.

Trow (1901) also has figured a similar content in the vacuoles of *Pythium ultimum*, but does not describe it so as to give any idea of its true nature.

A problem that has been most perplexing to me is how the protoplasm in the sporangium comes to be differentiated into a very dense layer at the periphery containing many nuclei, and a very loose structure in the interior with few nuclei. The purpose of such a differentiation is very evident, viz: That as much of the protoplasm as possible may be included within the spores, but just what propels the protoplasm up the sporangiophore and out toward the periphery of the sporangium is not so easy to determine. Arthur's (1897) explanation that it is due to evaporation of water from the surface, combined with absorption of moisture from the substratum, seems entirely inadequate. If this were the cause, we should expect to find the layer of denser protoplasm at the base of the sporangium as well as on the sides and top, as we have no evidence that evaporation does not go on from the part of the sporangium just around the sporangiophore as well as from the rest of the surface. Furthermore, from Arthur's explanation we should expect a gradual transition between the denser

and the less dense protoplasms, but, as has been already pointed out, the transition is quite sudden. Still further, the layer of dense protoplasm is not of the same absolute thickness for all sporangia, nor does it bear a constant relation to the size of the sporangium. The writer has been rather inclined to regard the thickness of this layer as dependent on the amount of available protoplasm, though by no means certain on this point. Arthur's conclusions bear more specifically on the streaming in the hyphæ than in the sporangium, and yet he gives us no intimation that he wishes to separate the two processes and refer them to different causes.

In the formation of the oosphere in some of the Peronosporeæ we have, according to Wager (1896), Stevens (1899), and others, a differentiation of the protoplasm into ooplasm and periplasm, but this differentiation is not characterized by such a marked difference in the density of the two protoplasms as in the Mucorineæ. The wall about the oosphere is described as forming on the boundary between two protoplasms. The question as to just how the protoplasm is divided and the wall formed has been pretty carefully avoided by all these authors. Stevens states that there is a thin film formed between the two protoplasms, and that this film seems to develop into the wall of the oospore, but his account of the process is very incomplete. Trow (1901) figures a stage in *Pythium ultimum*, in which the oosphere is only partially cut out, but, unfortunately, he does not describe it sufficiently to give us a clear conception of the real nature of the process.

The fact that the columella cleft forms just inside the denser plasm, rather than between it and the looser plasm, accords well with the idea that the cleft is formed by cytoplasmic contractions. The layer of denser plasm inside the columella cleft seems to be for the specific purpose of aiding in the cleavage by its contraction, a function that the looser plasm is probably unable to perform.

SUMMARY.

The essential processes in the formation of the spores in the sporangia of *Rhizopus* and *Phycomyces* may be summarized as follows:

1. Streaming of the cytoplasm nuclei and vacuoles up the sporangiophore and out toward the periphery, forming a dense layer next the sporangium wall and a less dense region in the interior, both containing nuclei.

2. Formation of a layer of comparatively large, round vacuoles in the denser plasm parallel to its inner surface.

3. Extension of these vacuoles by flattening so that they fuse to form a curved cleft in the denser plasm; and, in the case of *Rhizopus*, the cutting upward of a circular surface furrow from the base of the sporangium to meet the cleft formed by these vacuoles, thus cleaving out the columella.

4. Division of the spore-plasm into spores; in *Rhizopus*, by furrows pushing progressively inward from the surface and outward from the columella cleft, both systems branching, curving, and intersecting to form multinucleated bits of protoplasm, surrounded only by plasma-membranes and separated by spaces filled with cell sap only; in *Phycomyces*, by angles forming in certain vacuoles containing a stainable substance and continuing outward into the spore-plasm as furrows, aided by other furrows from the columella cleft and dividing the protoplasm into bits homologous with and similar to those in *Rhizopus*, and separated by furrows partly filled with the contents of the vacuoles that assist in the cleavage.

5. Formation of walls about the spores and columella, and, in the case of *Rhizopus*, the secretion of an intersporal slime.

6. Partial disintegration of the nuclei in the columella.

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DESCRIPTION OF PLATES.

[All the figures were drawn with the aid of a Leitz or a Zeiss camera lucida, with objectives and oculars, as follows: Fig. 1, Leitz *No.* 1 objective, *No.* 0 ocular; figs. 5, 6, 7, 8, 10, and 12, Leitz $\frac{1}{12}$ oil-immersion objective, *No.* 0 ocular; fig. 14, Leitz $\frac{1}{12}$ oil-immersion objective, *No.* 3 ocular; figs. 15, 17, 18, and 19, Zeiss 2 mm. 1.30 aperture, oil-immersion objective, *No.* 1 Huyghenian ocular; figs. 2, 3, 21, 24, 26, and 27, Zeiss 2 mm. 1.30 aperture, oil-immersion objective, *No.* 6 compensating ocular; figs. 22, 23, and 25, Zeiss 2 mm. 1.30 aperture, oil-immersion objective, *No.* 12 compensating ocular; figs. 4, 9, 11, 13, 16, and 20, Zeiss 2 mm. 1.30 aperture, oil-immersion objective, *No.* 18 compensating ocular.]

PLATE I. *Rhizopus nigricans.* Fig. 1.—Group of sporangiophores bearing sporangia, showing how they grow out from the stolon. × 12. Fig. 2.—Longitudinal section of young stolon, showing distribution of cytoplasm and nuclei. × 750. Fig. 3.—Same, except that the stolon is much older; wall very thick, and nuclei disintegrating. × 750. Fig. 4.—Disintegrating nuclei from stolon shown in fig. 3. × 2,250. Fig. 5.—Young sporangium, showing cytoplasm and nuclei streaming up the sporangiophore into the sporangium and out toward the periphery. There are a few crystalloids in the center. × 520. Fig. 6.—Sporangium that has attained nearly its full size. The differentiation between the looser and the denser plasms is sharply marked, except at a few places. Just inside the denser plasm is a clear zone of protoplasm that does not take the orange stain, and through this run strands of orange-staining cytoplasm bearing nuclei. × 520.

II. *Rhizopus nigricans.* Fig. 7.—Full-sized sporangium, showing layer of vacuoles nearly formed in the denser plasm. The two layers of the wall are here shown. × 520. Fig. 8.—Section cut through sporangium a little to one side of the sporangiophore. The columella cleft is being formed by fusion of the vacuoles shown in fig. 7, and by a surface furrow. The spores are also being cut out by progressive surface furrows. × 520. Fig. 9.—A small part of the same sporangium as shown in fig. 8, drawn from another section, showing in detail very early cleavage furrows, and structure, size, and distribution of nuclei and vacuoles. × 2,250.

III. *Rhizopus nigricans.* Fig. 10.—Cleavage much farther advanced than in figs. 8 and 9. Furrows cutting outward from the columella cleft. Section not cut through sporangiophore. × 520. Fig. 11.—Nuclei from columella of same; *a*, very close to columella cleft; *b*, *c*, and *d*, nearer the center; *a* has a normal structure, while *b*, *c*, and *d* show stages in disintegration. × 2,250. Fig. 12.—Sporangium in which the spores are completely formed, rounded up, and surrounded by thin walls. The columella wall is also formed. × 520. Fig. 13.—Nuclei from columella of same; *a* lies near columella wall and still retains its normal structure; *b* lies near it but is beginning to disintegrate; *c* and *d* lie near the center and are reduced to homogeneous angular masses. × 2,250. Fig. 14.—Ripe spores in their living condition, showing variations in size and ridges on walls. × 950.

IV. *Phycomyces nitens.* Fig. 15.—Young sporangium, showing cytoplasm nuclei and vacuoles streaming up the sporangiophore and out toward the periphery of the sporangium. Vacuoles in the denser protoplasm have a visible content. × 550. Fig. 16.—Small part of young sporangium very highly magnified, showing early stage in the formation of the visible

content of the vacuole; also two much smaller vacuoles with no such contents; nuclei in resting condition. × 2,250. Fig. 17.—Portion of cross section of sporangium at a somewhat later stage than fig. 15, showing distribution of protoplasm into an outer dense layer, an interior region of very loose protoplasm containing empty vacuoles and no nuclei, and between these two a layer of intermediate density. × 550. Fig. 18.—Part of longitudinal section of sporangium, showing layer of vacuoles forming in denser protoplasm where the columella is to be cut out. × 550.

PLATE V. *Phycomyces nitens.* Fig. 19.—Layer of vacuoles in the denser plasm, flattening out toward each other to form the columella cleft by their fusion. The contents flatten out also, taking the shape of the vacuoles. × 550. Fig. 20.—Small part of section very highly magnified, showing three vacuoles in contact, separated only by their membranes; also three very small empty vacuoles and six nuclei in resting condition. × 2,250. Fig. 21.—Spore plasm being cut up into spores by vacuoles becoming angular, and the angles cutting through the protoplasm as furrows; cytoplasm in front of furrows undifferentiated; nuclei in a resting condition. The contents of the vacuoles extend out into the furrows and fuse as the furrows fuse, to form the intersporal substance. × 750. Fig. 22.—Furrows cutting outward into the spore plasm from the columella cleft; cytoplasm in front of furrows undifferentiated. × 1,500. Fig. 23.—Furrows from the vacuoles cutting out to the plasma-membrane at the periphery of the sporangium. × 1,500. Fig. 24.—Nearly ripe spores containing resting nuclei and empty vacuoles, and embedded in intersporal slime. × 750. Fig. 25.—Living, ripe spores; walls smooth; *a*, very large; *b*, average size; *c*, very small. × 1,500. Fig. 26.—Very large peculiar-shaped spores; *c*, probably due to arrested cleavage. × 750. Fig. 27.—Very large, irregular-shaped spore due to arrested cleavage. × 750.

VI. *Pilobolus crystallinus.* (Diagrammatic and much simplified.) Fig. 28.—One-half of longitudinal section of sporangium just before the cutting out of the columella. The arrows indicate lines of contraction of the cytoplasm to form the columella cleft. Green arrows indicate points where the contraction is just beginning and red arrows points where the contraction is at its maximum strength; dotted black lines represent planes where cleavage is to take place. Fig. 29.—Same, but somewhat older stage; vacuoles flattened to fill the spaces where the cytoplasm has been pulled away; also surface furrow at the base of the sporangium. Blue arrows indicate points where contraction has passed its maximum strength. Fig. 30.—Columella cleft completed, spore formation just ready to begin. Fig. 31.—Vacuoles in the spore-plasm becoming angular, and furrows cutting inward from the periphery and outward from the columella cleft, due to the cytoplasm pulling away at these points. Fig. 32.—*Synchitrium decipiens.* (After Harper.) Two cleavage furrows cutting into the sporangium. These are slightly open at the inner extremity where the cytoplasm is contracting, but closed nearer the periphery of the sporangium where contraction has ceased. Fig. 33.—*Fuligo varians.* (After Harper.) Two furrows cutting into the spore plasm; furrows slightly open throughout their entire extent. Fig. 34.—Squid. (After Watasé.) Surface view of egg, showing cleavage furrows cutting into the cytoplasm between the nuclei; furrows very narrow at the extremities.

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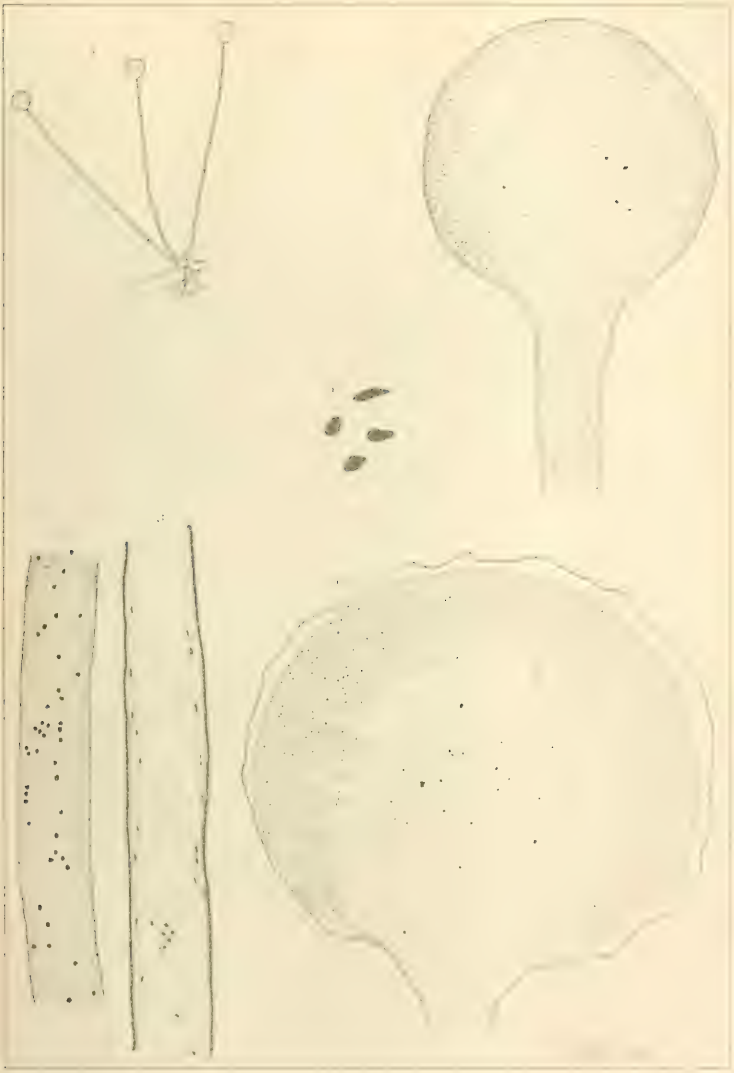

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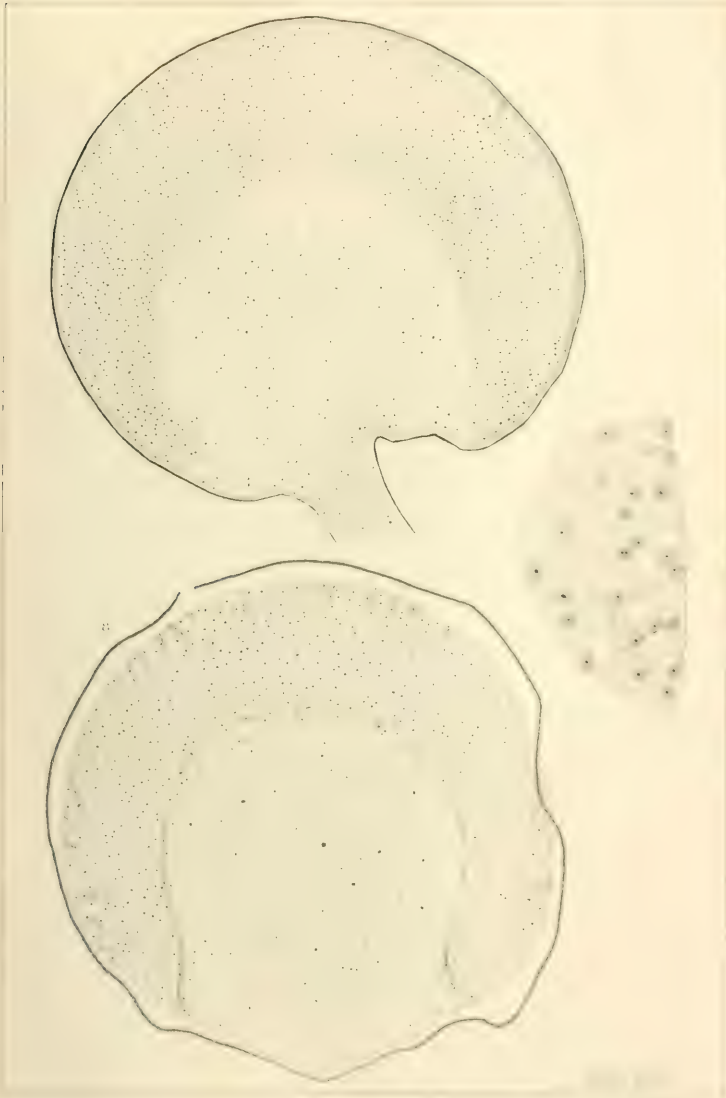

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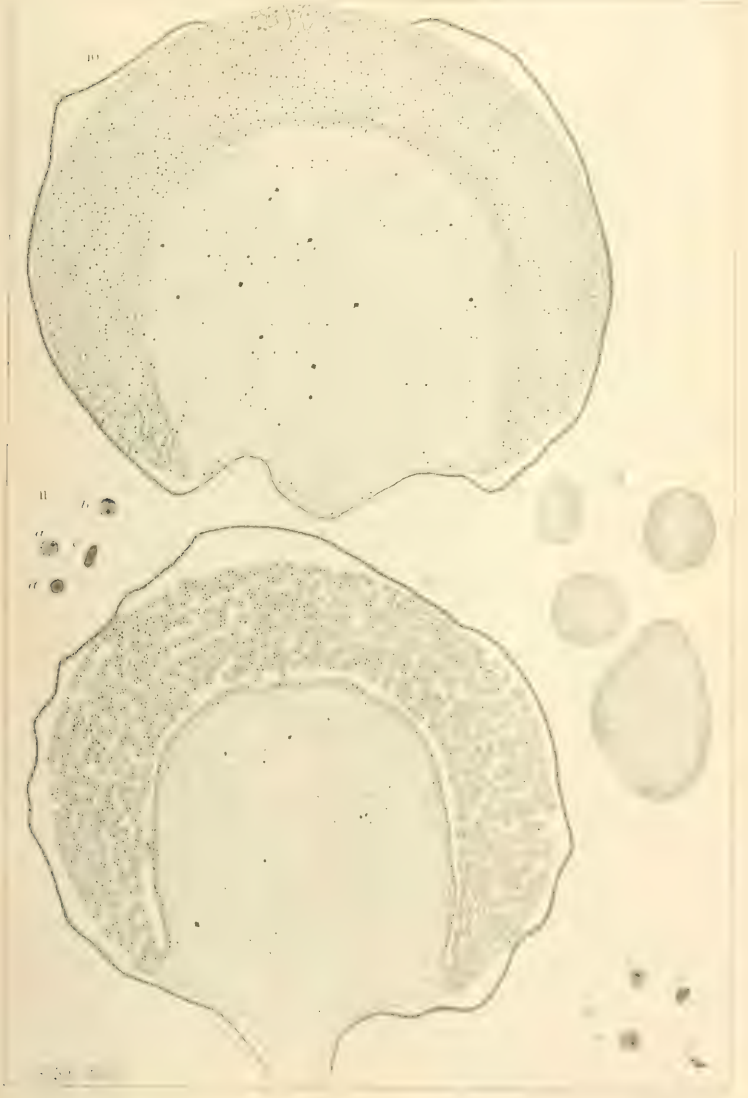

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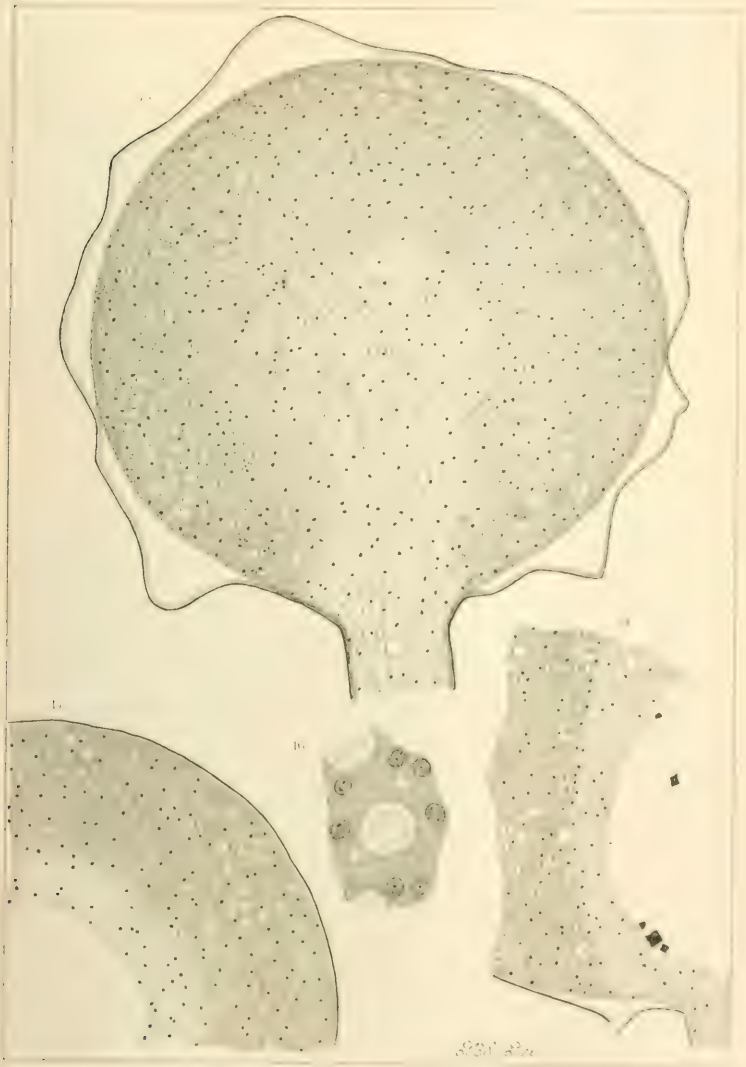

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